INDIAN SCIENCE CONGRESS ASSOCIATION

(REGISTERED UNDER ACT XXI OF 1860)

PROCEEDINGS
OF THE
FORTY-SECOND SESSION
BARODA-1955

PART II
LATE ABSTRACTS, DISCUSSIONS, LIST OF MEMBERS AND INDEX

1, Park Street, Calcutta - 16

FORTY-SECOND INDIAN SCIENCE CONGRESS

BARODA 1955

President :—PROF. S. K. MITRA, D.Sc., F.N.I., F.A.S.

PRESIDENTIAL ADDRESS

SCIENCE AND PROGRESS

THE STORY OF RADIO-ELECTRONICS

I must first express my deep appreciation of the great honour that my scientist colleagues have conferred upon me by electing me the General President of the Indian Science Congress Association.

I also offer our sincere thanks to our Prime Minister for coming to this Inaugural Meeting notwithstanding the innumerable demands on his time. Till year before last the Prime Minister had been attending our Inaugural Meetings as an honoured guest. But, he has since accepted the Honorary Membership of the Indian Science Congress and, as such, is attending today as one of us. The Prime Minister always places science in the forefront of any plan of national development. His acceptance of our Honorary Membership is a proof—if indeed any such proof is needed—of his belief that in the progress and applications of science lie the means of fighting the evil combination of poverty, ignorance and disease in our country. This belief of his is shared by all of us, the members of the Science Congress assembled here. But, I am afraid, there are still persons amongst the general public—and a considerable number of them--who have, at best, a confused idea about the rôle of science in the economic uplift of the country. And, even amongst knowledgeable persons, there exists not infrequently, a doubt about the urgency of conducting scientific research in the country. Hence, as one of the objectives of the Indian Science Congress is to disseminate the knowledge of science and its applications I would, in the first part of my address, make a few remarks regarding the rationale of this rôle. What I will say will not constitute a learned thesis and will not contain anything new that is not already known to my scientist colleagues. It will rather be an appeal : An appeal to the general body of intelligentsia of the country to try to understand clearly, without allowing the main issue to be clouded by sentiment, the root cause of mass poverty and the right method of fighting it, and also to give intelligent support to the plan for carrying out the fight--the Five Year Plans adopted by the State.

I. RÔLE OF SCIENCE IN ECONOMIC PROGRESS

Science and national reconstruction.—The economic progress of a country depends on the extent to which its natural resources have been exploited for creation of wealth, that is, for production of commodities of human need. Without such exploitation there may be the curious spectacle of a country which is rich in natural resources but whose people are poor. The spectacle is like that of a man who possesses wealth but who has to live in poverty because his wealth is locked inside a vault and he

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has not the key to open it. Science provides the key for unlocking the wealth. Speaking without metaphor, science, enquiring into the laws and regularities of Nature, indicates the methods of utilising the natural resources of the country for the production of the necessities of life and for their efficient distribution. Mere indication of the methods is, however, not enough. To implement the methods indicated one has to do work. And here again science comes to the aid. Science provides labour saving devices, power, machineries and tools, for doing the work—devices of all types, those for work involving only muscular effort, for work demanding manipulative skill and, in recent years, even for work necessitating brain effort. Without such aids the rate of production is extremely slow and the country can not produce enough to become wealthy by any standard.

In the light of the above, the origin of poverty of the masses in India can be put in plain language thus: In order to get the comforts and amenities of life one must work. The amount of work necessary for supplying these, according to modern standard, is beyond the capacity of man and animal power. The western countries employ for this purpose labour saving machineries. India does not do that to the same extent. Hence India can not enjoy the same comforts and amenities as the western countries do. If India aspires to attain the status of a rich nation she must adopt the policy of making the fullest use of the natural power and the labour saving machineries for increasing her production, that is, must industrialise herself. This is plain and simple truth and can be understood by the man in the street. But, strangely enough, when attempt is made to give effect to the policy difficulties are found to arise. I well remember, in this connection, what I was told more than a decade ago, when I visited a near-by industrial city as one of the members of the Industrial Research Planning Committee appointed by the Government of India. The manufacturers said, "We agree that scientific research will most certainly point the way to increased production. But will there be enough demand for the goods so produced?"* Even to-day, the same thing is said by the industrialist. We have thus the dilemma: people can not purchase and support the industries because they are poor and the people are poor because there are not enough industries in the country. Then there is another dilemma. The industrialist asked to rationalise his methods of production says: I am ready to rationalise, but that will throw men out of their jobs and aggravate the problem of unemployment. The reason why these dilemmas arise is that in the policy of industrialisation emphasis is, not infrequently, put on the wrong end. In order to be fully effective industrialisation must proceed in an ordered fashion and not haphazardly. The right order of emphasis should be capital goods (machinery, steel, power plant, etc.), production goods (fertilizer, steel, heavy chemicals, etc.) and consumer goods (light electrical goods, paper, clothing, etc.) industries. If emphasis is laid on the last named ones first, the problem of overproduction is bound to arise, because, the purchasing power of the people can not increase out of nothing. In this connection one may consider the case of agriculture—a major and vital industry of any country (belonging to the last category). Since 80% of our population is dependent on agriculture—pursued primitively with hand and animal power—it is tempting to begin by laying emphasis on mechanisation of agriculture. But one forgets in ones enthusiasm that if mechanisation is pushed too far, without having started industrialisation in other sectors, the agriculturist will be thrown out of employment and, at the same time, the lowered price of his produce will hit him adversely. The lowered price, in fact, will benefit the 20% non-agriculturist and not the agriculturist. If, however, one starts with emphasis on the establishment and expansion of the capital goods and production goods industries, then, on the one hand, jobs will be created instead of destroyed absorbing men from the agricultural population, and, on the other, the consumer goods industries will be helped by the supply of production materials. The consumer goods industries, at the same time, will receive stimulus by the increasing purchasing power of the workers of the newly created industries. This will be a move in the right direction, right for progressive industrialisation and not in the direction in which industrialisation produces problems of unemployment and overproduction. Such progressive industrialisation will also ultimately bring about the much sought for transition of the economy of the country from one predominantly agricultural to one predominantly industrial.

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* It is pleasant to note that the industries referred to above have, since, combined to form a Research Association and have founded a fine Research Institute with the co-operation of the Council of Scientific and Industrial Research.

I hope I shall not be misunderstood as having advocated neglect of agriculture. Agriculture, or for the matter of that, all village industries should have to be fully mechanised ultimately, because, rural economy based on hand-loom and primitive agriculture will never raise the standard of living of the villager above subsistence, though, some of our politicians still dream of effecting this by giving support to village handicraft, perpetuating inefficient and outdated methods of production.* What I meant was that by giving prior emphasis to agriculture we shall only be endorsing the policy of the Government of the pre-independence days which had always said that since India is predominantly an agricultural country her salvation lay in improving her agriculture.

Effecting the transition from agriculture to industry is not a simple and easy task and there is no short cut to it. Vast amounts of capital goods in the shape of machinery, power plant, land and buildings will be needed for the purpose. The formation of the necessary capital—if we are to depend on the peoples savings only—will take time, because savings of the people are meagre. The problem is further complicated by the rapid rise in population. There will, in fact, be a race between the increasing earining capacity of the capital formed and the increasing population. If the formers wins we shall be richer and richer. If the latter wins we shall be poorer and poorer. And, if neither wins we shall continue to be as poor as we are today notwithstanding our industrial developments. (If population growth is not controlled, then, according to some estimate, the investment rate has to be Rs. 2,000 crores per annum for the next few years to double the national income in 10 years.) Besides, even supposing that the capital is progressively built up and invested, the transition will have to proceed according to well thought out plan. The developments in the different sectors—agriculture, the various capital, producer and consumer goods industry, power production and social services and will have to be so co-ordinated that the growth of one will stimulate the growth of others and will ensure the most rapid progress of the country as a whole. This requires planning on a comprehensive scale—Total Planning. Without such a total plan we shall be more planned against than planning. (I hope to be excused for using the word "Total" but I could not find a better substitute.) That the planning, in order to be effective, has to be comprehensive and total was recognised by our Prime Minister even in pre-independence days. In 1938, he accepted the chairmanship of the National Planning Committee set up by the Indian National Congress and worked indefatigably for it till he was sent to prison—for the eighth time—in 1940. Even in prison he gave much thought to the problem of planning. (See, for example, *Discovery of India*, pp. 332-44). It is, therefore, a matter of great satisfaction that the Planning Commission has been set up by the Central Government. Notwithstanding criticisms, the Commission has achieved significant results in the First Five Year epoch soon coming to a close. After years food shortage, the country has attained self-sufficiency. But, there is yet no ground for complacency. There are still hungry and half-fed people in the country. We have been able to meet the food demand, but not the food want of the people. We have yet a long way to go to be able to equate want with demand and thus to reach the goal of the plan. But, to reach the goal—no matter how thoroughly the plan is made—it is essential that we have peace—peace not only in the international sphere, but also domestic peace. It is often said that the U.S.S.R. has achieved wonders by her Five Year Plans. A very large measure of this success is no doubt due to the objective thoroughness of the Plans ; but it is also in no small measure due to her having internal peace, no strike, no industrial dispute. In our country also if the plans are to succeed there must be complete understanding and full co-operation between workers of all classes in industry, in business and in every other occupation. The workers—amongst whom I include both employers and employees—must realise that they should, in their own interest, maintain peace and work wholeheartedly for the success of the Plans. Because, wealth and prosperity resulting from the success will benefit and will be shared by both.

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* Those who think in terms of village handicraft may consider the following figures. A man working continuously can wield one-tenth horse-power (H.P.). If he works for 8 hours a day, his output of work in electrical unit is 0·6 kilowatt-hour (1 H.P. = ·746 K.W.). Assuming that the average man works only 300 days in the year, and that in a population, excluding the sick, the children and old only one-third can be engaged in manual labour, the average output of human labour comes to $300 \times 6 \times \frac{1}{3} = 60$ units per capita per year or 1/6th unit per capita per day.

An ordinary electric fan consumes the latter amount of energy in about 2 hours. This shows how poor is the average output of human labour of a country.

Place of scientific research.—I will next try to answer the question sometimes asked : What is the urgency of establishing research institutes and of carrying out researches in the country, when the fruits of the applied sciences, the labour saving devices and the methods of production, at least those employed in the principal industries, are available in the western countries? The answer to this question is that importation of ideas and goods from abroad—though always necessary—is not enough. Problems arise in connection with the processes of production in even well established profit earning industries and also with the utilisation of the natural resources which are peculiar and special to the country concerned. Clear understanding of such problems needs scientific approach and their solution scientific guidance. This is only possible if the country has her own trained scientists and her own research laboratories and organisations. It is also to be noted that, not infrequently, researches concerning the problems and the difficulties to be solved lead to invention of new processes of production, and improvements of the existing ones. And, above all, one must not forget that applications of new scientific principles are almost invariably followed by technological developments which give rise to new industries creating wealth. Part of the wealth so created always finds it way back to the organisations for research and for the training of research and technical personnel. The research activities thus intensified lead to fresh scientific discoveries from which again flow new technological developments providing newer means of creating wealth. This is the process we are witnessing in the western countries, the rising spiral raising their people to giddy heights of prosperity.

The economic and cultural advancement of a country is, in fact, today judged by the number of scientists it engages in proportion to its population. According to the Steelman Report (Report to the U.S.A. President by John R. Steelman, Chairman of the President's Scientific Research Board) the proportion in the U.S.A. in 1956-57 is expected to be about 2 per thousand. This is also the proportion believed to be in the U.S.S.R. For Great Britain the proportion is ½ per thousand. According to some authorities the target for a progressive country should be 3 per thousand.

Fortunately, we in India have not been entirely unmindful of the value of scientific research for the economic advancement of the country. For some considerable time there had existed in the country government organisations for research in agriculture, in irrigation, in forestry, in the medical and veterenary sciences, and for surveys in geology, botany and zoology. About a decade and a half ago the Central Government adopted the policy of giving general support to both fundamental and applied researches and established the Council of Scientific and Industrial Research. Also, with the advent of the Atomic Age at the close of World War II, an Atomic Energy Commission was appointed in 1948 for the purpose of developing atomic raw materials, for setting up a nuclear reactor and generally for nuclear research.

Every thinking Indian regards these scientific institutions as assets of utmost value to the country. The C.S.I.R. has been sponsoring researches in the University Laboratories and other institutions, has helped in the formation of Research Associations by some of the industries and, above all, has established a chain of National Laboratories covering a range of subjects in science and industry. It is very necessary that to extend these activities of the C.S.I.R., the recommendations that have been made by its last Reviewing Committee receive due consideration from the authorities concerned. The Reviewing Committee, be it noted, was greatly impressed by all that has been accomplished and recorded its high appreciation of the devoted efforts of the Director, Scientific and Industrial Research, the late Dr. S. S. Bhatnagar. I would, in particular lay stress on the recommendation advocating the necessity of so orienting the relationship of the National Laboratories and the Institutes with the universities that the whole scientific organization may be operating in concert. This is because, as the Reviewing Committee has very pertinently pointed out, "The future depends to a great extent on the education *by the Universities* (italics are mine) of young people of high calibre to man the laboratories and to fill, while they are still in full vigour, posts of responsibility."

The country also expects great things of the A.E.C. India, as is well known, has not a large reserve of coal, the source most widely used for generation of power. In fact, her reserve is extremely small compared either to countries like the U.K. and the U.S.A. which are already highly industrialised or to a country like China which is on the way to industrialisation. It is, therefore, of utmost importance that sources of power generation other than coal be searched for from now. The only other source which can seriously take the place of coal is atomic energy. It may be noted, in this connection, that the U.S.A., the U.K. and the U.S.S.R. have already begun generating electricity from power derived from reactors, though, the cost is still higher than that generated from coal. It is, therefore, hoped that the most important objective of the A.E.C. will be that of building atomic reactors out of Indian materials and also carrying out researches on economic power reactor development. Undue stress need not be laid on secrecy, because, after all, we shall be carrying out atomic investigations for peaceful ends only ; secrecy leads to sterilization by naturally putting the responsibility on the shoulders of only a few.

It is, also hoped that in the Second Five Year Plan, allocation of expenditure on research will be on a scale more generous than what it has been in the First Five Year, which was only a small fraction of the 2·5% of the total expenditure allocated under heading Miscellaneous. It may not be out of place to refer here to expenditures on research and on organisation of scientific efforts in the U.S.A. and in the United Kingdom, though, a large part of it is for defence purposes. Leaving aside the large sums spent on research in relation to the industries by the various industrial concerns, the Federal expenditure on research in the U.S.A. is more than 2,000 million dollars per annum. This is exclusive of the huge sums spent on Atomic Energy (more than 400 million dollars) and on Aeronautical Research. In the U.K. the annual government expenditure on research is of the order 225 million pounds. (In this case the expenditure is inclusive of that on researches in relation to aircraft and to atomic energy development.) Besides, more than 30 million pounds is spent annually by the British industry on research and development within its own establishments. (This is 1947 figure, representing about 0·7 per cent of the total annual value of British manufacture). We in India can not, of course, expect the Governmental expenditure on research to be as lavish as in the U.S.A. and the U.K., nor, in the existing state of our industrial and other developments, we need such large expenditures. It is still felt, however, that the amount allocated for research is small and should be more than what it has been under the First Five Year Plan. With a more generous allocation it will not only be possible to make more generous grants to the Government Research Organizations, but also to give liberal aids to such of the individual research workers in the Universities and in the non-official research institutes, who, by their devoted efforts, have built up centres of research in special branches of science. Such grants will greatly encourage fundamental and applied research.

I have pleaded thus for increased scientific effort, because, I firmly believe, and, I am sure this belief is shared by the scientific workers of all countries, that principles of scientific discoveries properly utilised for production and distribution, and not for destructive purpose, can provide sufficiency for all.

II. THE STORY OF RADIO-ELECTRONICS

As an illustration of what I have said in the first part of my address concerning technological developments flowing from applications of scientific principles contributing to the general progress of mankind, I will, in the second part, tell you the story of the birth and growth of the twin sciences Radio and Electronics or, Radio-electronics in short. I have chosen this subject partly because I have spent many years of my life in the organisation of its teaching and research and partly because the subject is of great national interest having given rise to one of fastest growing industries of the world, producing goods not only for civilian and industrial use but also for vital defence needs.

Radio-electronics with its innumerable ramifications is too vast a subject for even a brief survey in an address like this. I will, therefore, only touch the high lights. Further, since the subject is of great popular interest, I will try to make the address intelligible to all. It will therefore be somewhat of a popular nature. But, I do not apologise for it. Much of what I will say is well known to the physicists and radio specialists. But

I hope they will have a little patience for the sake of the majority here who may be ignorant of them.

I begin by trying to define the subject Radio-electronics, though, it is difficult.

Radio.—The word radio is derived from radiation*, meaning specially electro-magnetic radiation, or, electric oscillations. Radio is the art of communicating messages across space without the use of connecting wires. The message to be communicated may be in simple dots and dashes, in sound of varying pitch and intensity, in writing or picture, or as a living scene.

Radio was born on the day on which Heinrich Hertz, the German scientist produced electromagnetic waves—the carrier of all such messages —by discharging an electrified condenser across a spark gap circuit (1887).

Electronics.—Electronics is the science and the art of controlling the movement of electrons, the light negatively charged particles which surround the massive atomic nuclei. The electrons are easily detached from the atoms and their existence was discovered towards the close of the last century in the course of studying the phenomena of electric discharge in partially evacuated glass vessels (like the modern neon sign tubes).

The discovery of electron can not be ascribed to any single individual. The many phenomena observed in the course of experiments on electric discharge in glass vessels evacuated to various degrees (carried out mainly at Cambridge, England, by J. J. Thomson and his school towards the end of the last century and the beginning of the present one) could only be explained on the assumption of the existence of free electrons in the vessels. The name *electron* is due to Johnstone Stoney, who, much earlier, had suggested the particle character of electricity (1874).

Neither the discoverer of the electromagnetic waves, nor those of the electron could have foreseen the amazing developments that were to follow these discoveries in the course of a few decades, discoveries made in the course of investigations carried out purely in the spirit of research. In the case of electromagnetic waves it was to check Clerk Maxwell's mathematical deductions on the unity of light and electromagnetism made 23 years earlier, and in the case of electron to understand the composition of atoms.

Radio-Electronics.—The spectacular development of the art of radio that we have witnessed, culminating in some of the greatest wonders of the modern age—the radar and the television—has been possible only because of the parallel development of many electronic devices and the utilisation of the same in radio technique. On the other hand, results of many investigations connected with radio circuitry have found their place in the art of electronics and have made possible its many successful applications. The growth of the one has thus helped in the growth of the other. Thus has grown up what may be called radio-electronics, which is radio and electronic techniques at work in new ways and in diverse fields of human activity.

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* The terms *radio* and *wireless* are now used almost synonymously. But it has not been so always. It appears that *radio* was for the first time substituted for *wireless* by the Germans in the articles of the International Wireless Telegraph convention in Berlin on November 3, 1906. It was, however, not until the advent of broadcasting (early twenties of the present century) that the term radio began to be currently used in other countries. The great wireless operating companies in the U.S.A. were "wireless" until 1918. "Wireless" is still in common use in Great Britain.

The revolutionary developments that followed Hertz's experiments and the discovery of electron in evacuated glass vessels proceeded in three distinct stages :

In the first stage there was the development and perfectioning of wireless telegraphy. This was in the period between the closing years of the last century and the years immediately preceding World War I.

The second stage began with the invention of two-electrode and three-electrode electronic valves for use in wireless telegraphy and telephony, and thus ushered in the age of radio-electronics. The age also saw the advent of short waves for round the world communication leading to the discovery of the Ionosphere—the radio roof of the world. The stage roughly covers the period intervening the two world wars.

The third is the present stage—the age of Microwaves—waves in the centimetre range. In them radio-electronics has found an entirely new field of applications.

The future stage, if one may venture to make a prophecy, will be the era of the uses and applications of the element *germanium,* the wonder child of electronics. We are on the threshold of this era. One foresees with a certainty the advent of radio equipments of unbelievably small size replacing many of the cumbrous and heavier ones in use today. And, at the same time, as it had happened before with a fundamentally new invention—there will open up many new fields of application of radio-electronics.

THE FIRST STAGE

The Age of Wireless Telegraphy

The story of the first stage of development—the utilization of Hertzian waves for signalling across space—is well known and needs only a brief reference. In this stage wireless came to be increasingly used for long distance communication supplementing submarine cable service and, not infrequently, totally supplanting the same. Wireless also was adopted by the steamship companies and by the Navy as a means of communication between two moving vessels, or between a moving vessel and a fixed land station. It was also adopted by the Defence Services as an indispensable aid to army manoeuvre. The technical developments in this stage consisted in the installation of long and very long wave (12,000 to 30,000 metres) transmitters and erection of tall masts carrying extended aerial systems for increasing the range of the service. At the beginning, the electric oscillations were produced by simple adaptation of the Hertzian oscillator. This, however, generated trains of highly damped wave packets, which were not only wasteful to produce, but were also not well adapted for tuning. Novel forms of spark gaps like the so-called syntonic spark gap were, therefore, devised to minimise the damping. Ingenious devices were also invented to do away with the spark gap altogether and generate continuous oscillations. Thus were evolved high frequency alternators like the one associated with the name of Alexanderson and the arc oscillator like that of Poulsen. Attempts were also made at wireless telephony, that is, transmission of speech as opposed to dots and dashes with some success.

This passing reference to the first stage of development would be incomplete without a mention of the controversy that has arisen in recent years regarding the real inventor of wireless. Popularly, the name of

Marconi is associated with this invention. But a few years ago it was claimed that the distinction of being the first man to utilise the Hertzian waves for signalling across space should go to the Russian physicist-engineer Popov. Evidences were produced to show that Popov was not only the first to use earth connected elevated aerials for efficient radiation and collection of electric waves, but also was the first to use them for signalling across space. Counter claims by Marconi's supporters were put
Marconi is associated with this invention. But, a few years ago it was
forward and the controversy, I am afraid, is still unfinished. Be that as it may, a correct statement of facts concerning the invention of wireless would be to say that of the many scientists immediately following Hertz and interesting themselves in researches on electric waves, there were a few—including Sir Jagadish Chandra Bose in India—who, purely in a spirit of research, had experimented with these waves for signalling across space. But, amongst them Marconi was certainly the first to realise fully the enormous commercial possibilities of the Hertzian waves, and the stream of developments that followed Hertz's work was also mainly due to him.

THE SECOND STAGE—ADVENT OF THE THREE-ELETRODE VALVE

The Age of Radio-Electronics

The story of the evolution of the three-electrode valve which ushered in the age of radio-electronics is as follows:

In 1883 the great inventor Thomas Alva Edison, while developing his electric lamp discovered that if an isolated metal plate is sealed inside the lamp bulb, an electric current would flow between the incadescent filament and the plate if the plate is made positive, but not if it is made negative. Edison did not follow up this far reaching discovery of his—the *Edison Effect*. We now know that the current was due to the flow electrons, emitted by the hot filament, across the gap between the filament and the plate. In 1904, J. A. Fleming an English physicist utilised the Edison effect for constructing the diode or the two-electrode Fleming valve. The diode was put into commercial use by the Marconi Company for detecting wireless signals picked up by the receiving aerial. In 1908, Lee de Forest, an American engineer, introduced between the plate and the filament of the Fleming valve a third electrode (grid) for controlling the flow of the electronic current by controlling from outside the charge on the grid. The 'Audion', as this device was called by its inventor, was put into certain uses, but, lay in comparative obscurity for a number of years. This was chiefly because of its erratic behaviour due to the presence of residual gas inside. Perfectioning of the vacuum and thus making its use more reliable was the work of other investigators, mainly that of Irving Langmuir with the aid of high vacuum pump of his own invention. The revolutionary possibilities of the triode were realised only in 1914 when was invented the feed-back principle, by which a triode, correctly connected to a properly designed electrical circuit, could, on the one hand, detect and amplify extremely weak electric signals and on the other could generate electric oscillations.* Many of the subsequent improvements and modifications of the triode and the triode circuit were made during World War I by the belligerent nations under pressure of war exigency. These were made known after the war was over in 1919 when the world was presented with a practical system of radio telephony which immediately made possible the operation of long distance trunk telephony and also paved the way for broadcasting (1923).

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* **A distressing feature of the invention of the triode valve has been the many litigations in the field of patent rights that it gave rise to. In 1904, the Marconi Wireless Telegraph Company of America claimed that the de Forest Radio Telephone Company had no right to manufacture 'Audion' as it infringed the patent right of the Fleming valve. In 1916, the Court decided in favour of the Marconi Company holding that the de Forest Company could not manufacture the three electrode**

An interesting development of very great practical interest also followed. With the release of the triode valve for general use, there appeared on the scene the amateur radio experimenter. To play with, the amateurs were allotted the use of short waves (waves less than 200 metre length) as these were considered useless for practical long distance communication. The amateurs, however, soon discovered that they could do with these short waves just what, according to the radio *pundits,* they were not expected to be able to do. With power of a few watts (compared to hundreds of kilowatts of commercial stations) and simple homely aerials they began exchanging greetings with fellow amateurs in distant parts of the world. The experts at first received these reports with scepticism. But they could not shut their eyes to facts. They, therefore, began investigating the possible mode of long distance short wave propagation and were led to the re-discovery of the radio wave reflecting region of the upper atmosphere—the Ionosphere.

The many applications of the triode and of its modifications and of many newly invented electronic devices after the close of World War I, to the promotion of almost every form of human activity—education and entertainment, transport by sea and air, controlling industrial productions, medical therapy, offensive and defensive operations in land, sea and air and to researches in pure and applied sciences are too numerous for detailed description. I shall make only a passing reference to one, the electronic computing machine.

The history of high speed electronic computing machine or "giant brains" as they are called, is only about 10 to, 15 years old. Every such machine is basically composed of the following units: A computation unit, a control unit, and a memory unit. The first carries out addition, subtraction and division at incredible speed, the second directs and supervises the various operations and the third stores the information and instructions. There are also devices which feed the data and the instructions to the machine and also those which obtain the answers in intelligible forms. The computing unit can multiply 4000 times faster than a human computor and can add 30,000 times quicker than a computor. The actual speed of calculation for a particular problem may, however, be much lower because the information has to be supplied to the machine in a particular code. The basic difference is that electronic machine, unlike the usual decimal system, uses binary digit system for calculation. The major fraction of time is taken in encoding the computing matter in a particular fashion

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valve without the consent of the other party. Again, there was a litigation starting in 1914 and lasting for twenty years concerning the invention of the "feed back" system. The Court in this case awarded the credit of the invention to Lee de Forest. But it must be admitted that there had been other inventors like Langmuir and Hull of the G.E.C. Laboratories, Arnold of the Bell Telephone Laboratories, Meissner and Armstrong who contributed substantially to the practical development of the 'Audion' and to the clarification of its use as an amplifier. Special mention should be made of E. H. Armstrong, Professor of Electrical Engineering in the Columbia University, U.S.A., who was not only the first to explain clearly the action of the 'feed-back' principle, but was also the inventor of the super-heterodyne and the super-regenerative circuits and of the frequency modulation system.

suitable for the machine and this time varies from problem to problem. But even then the speed of these machines is enormously greater than what can be achieved by human computors. Due to this high speed, the electronic computors are finding new applications in the fields of science, engineering, and business organization. Amongst their many applications in science mention may be made of solution of differential equations with large number of variables, investigations in quantum mechanics and X-ray analysis of crystals. In the engineering field also electronic computors are finding increasing applications. Computors are used to analyse results of wind tunnel experiments, analysis of ballistic trials, flutter characteristic of aeroplane wings and complicated optical problems.

The use of computing machines is greatly speeding up the accumulation of knowledge. This accumulation is sure to have repercussion on the theoretical sciences. The accumulated knowledge may be expected to lead to the formulation of modifications of the existing theories, making them more powerful.

THE THIRD STAGE

The Age of Microwaves

Microwaves—waves in the centimetre range—had been used by the early investigators for their researches on Hertzian waves. Thus, Sir Jagadish Chandra Bose in India used waves as short as half-centimetre for his elegant experiments on the optical properties of Hertzian waves. However, at that time and also for many years afterwards waves of such short length were considered to be of only academic interest. Since the Second World War, however, these waves have assumed great importance. The reasons for this are as follows:

Firstly; special types of thermionic valves (involving principles entirely different from those employed in the three-electrode valve) have been invented with which one can generate continuously the extremely high frequency electric oscillations—tens of billions per second—necessary for such short waves. (The ordinary three-electrode valve becomes inoperative at such high frequencies because the time of flight of the electrons from one electrode to the other becomes comparable with the period of the oscillations.) It is pleasing to note that both of the two modern types of valve commonly used for generating microwaves—the klystron and the magnetron with cavity resonator—were invented in the University research laboratories, the former by the brothers R. H. and S. F. Varian of the Stanford University, U.S.A., and the latter by J. T. Randall of the Birmingham University, U.K.

Secondly, the waves on account of their short length can be focussed like light waves with compact devices and, when falling on a distant object, e.g. an aeroplane, can be scattered back with sufficient intensity to actuate a distant receiver built with modern refinements.* The microwaves can,

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* The energy returned by an object (metallic) is extremely small if the wavelength is large compared to the size. It attains a large value when the wavelength is resonance wavelength—which occurs when the wavelength is of the same order as the dimension of the object. For wavelengths lower than the resonance wavelength it decreases very slowly. The received power P_r is given by

$$P_r = \frac{C P_t S A^2}{R^4 \lambda^2},$$

where R=range; P_t=transmitted power; C=a constant depending on the type and efficiency of the antenna; S=a factor depending on the nature and size of the target; A=aperture of antenua; λ=wavelength.

in fact, be used just like search light for locating a distant object in the dark. The transmitter, with its focussing aerial, takes the place of the search light and the sensitive receiver with the cathode ray device that of the eye. There is, however, the great advantage that unlike the light waves, the microwaves pass freely through fog, haze and clouds. Thus has developed the wonderful technique of Radar (*R*adio *D*irection *a*nd *R*ange Finding), with its unlimited variations. One can, for example, follow the movements of an aeroplane from the ground or take from a plane the picture of a landscape hidden by clouds. One can control the course of a vessel or a plane from a distant station. The application of the principle has led to the evolution of the guided missile which can be made to follow the target by controls from the ground. There has also developed automatic control systems with the electronic brain—which does away altogether with the human element. An anti-aircraft gun, for example, will automatically train itself on an enemy plane or a rocket bomb when sighted by the radar, will follow its movements and, as soon as the target comes within its range will fire at it ; if the target does not come within the firing range the gun will move back to its rest position. Perhaps the last word in the perfection of such automatic fighting devices is the supersonic anti-aircraft missile which will follow and hit an enemy target regardless of any evasive movement on the part of the latter. The missile, in fact, is able to manoeuvre on its own throughout the flight, by picking up the scattered microwaves (microwaves which it itself had sent out) from the target.

Of the numerous other peaceful applications of the radar technique mention may be made of the radar control by which an aeroplane can land safely and rapidly at a rate previously deemed impossible and of the radar picturing of distant cyclones and regions of storm which provide safety and to sea and air navigation—specially to the latter.

Of the other uses of microwaves, one may mention the easy point-to-point communication along straight distances. Such system of communication has extended greatly in recent years in the U.S.A.

The perfectioning of the marvellous invention of the modern age, the Television, is also a result of direct application of the many new inventions and refinements of microwave and electronic techniques made during World War II. By means of microwave point-to-point communication or, by means of good quality co-axial cables, it will now be possible to relay television programme over long distances. The day is not far distant when it will be possible to sit in Baroda and see on the television screen topical news pictures transmitted from London, New York or Moscow.

Microwave propagation phenomena through the atmosphere (lower troposphere) has given rise to a new branch of meteorology—the radio-climatology. The propagation is affected by super-refraction caused by special types of height distribution of temperature and humidity in the lower troposphere. Radio-climatology attempts to correlate these phenomena.

The phenomenal development of microwave and electronic techniques that took place during World War II and which paved the way for further spectacular developments during the post-war period, would have taken many decades in normal peace time. The success has been due, on the one hand, to the spirit of team work between different groups of workers—scientists, technicians and engineers that prevailed during the war period and, on the other, to the lavish support from the State.

THE COMING ERA OF GERMANIUM

Germanium, element number 32 in the Periodic Table, was discovered by the German Chemist Winkler in 1886 and was named thus after his native land. The importance and the possibilities of Germanium in radio-electronic devices lie in the fact that two mechanisms of electrical conductivity—the *n*-type, due to electrons as carriers, and the *p*-type, due to positively charged "holes" as carriers,—can be induced and controlled in this non-conductor by deliberately introducing certain kinds of impurities into it. (These impurities are of the order of one part in one thousand, and are called 'donors' which produce electrons and 'acceptors' which produce 'holes'.) The possibility of the existence of the two types of carriers endows the crystal with tremendous possibilities, for, in such an event, the electrical properties of a region having a certain type of carrier may be easily altered by injecting into the same those of the other type. The region of contact of two crystal samples, one with electrons and the other with 'holes' as carriers, therefore, becomes a seat of great interest and possibilities. Of these, the triode action is the latest and the most significant.

The story of the successful application of germanium to the invention of the transistor -which can replace a triode valve in many of its functions —affords a striking example of how fundamental research leads to first class practical inventions of far reaching importance. The story is as follows :

In the Bell Telephone Laboratories at Murray Hill, N.J., U.S.A., there is a research group known as the "Solid State Physics Group". The business of this group for many years had been to investigate the properties of semi-conductors, not merely because of their useful electrical applications, but also because of their rich scientific interest. Now, the usefulness of semi-conductors in electrical application lies in the fact that their indifferent conductivity due to poor supply of current carrying electrons (of the order one electron per million atom as compared to one electron per atom in a good conductor) can be altered over a wide range- varying about 100 fold —by varying the electronic structure of the material. In the middle of the last decade Dr. Shockley of the Solid State Physics Group had been examining critically the implications of the current theory of electrical conduction in semi-conductors. As a result of this examination, he predicted that the meagre supply of electrons in a semi-conductor ought to be controllable by influencing them with an electrical field imposed from outside without actually contacting the material". Dr. Shockley was quick to realise the practical importance of his deduction and devised some test experiments to check his hypothesis. But, unfortunately, he could not obtain any positive result. The electrons failed to behave according to his prediction. They were somehow trapped in the surface of the material. Dr. John Bardeen, also of the Solid State Physics Group, now attacked the problem theoretically. The theory he developed showed what happened at the surface and also explained many of the observed facts satisfactorily. Further experiments were now carried out in collaboration with Dr. Brattain, another member of the Solid State Physics Group. These experiments led to the invention of the transistor.

Besides its use as transistor—which replaces triode valves in many of their applications—the germanium has two other uses as electronic components. These are, its use as detector as in the old "cat's whisker" crystal radio set and its new commercial use as rectifier.

Germanium junction rectifiers are now used in television sets, in radio receivers, in electronic computers, in 'walkie-talkies' and in many other equipments for civil and military use. They replace diode valves in their respective fields quite efficiently.

The transistor is now available in two different types, viz. the point contact and the junction type. It saves space and power and is impervious to blows, shocks and vibrations. Though the transistor has certain drawbacks—its use at high frequencies being limited and its noise figure being large—efforts are being made by research engineers to eliminate them. These efforts have already led to several new developments, of which the crystal tetrode deserves special mention. The great future of transistor can be visualised if it is remembered that a transistor does not need an L.T. battery and that its weight and the space it occupies are many thousand times smaller than those of a conventional triode.

It is interesting to note that very little of germanium used commercially is mined. Most of it used at present is recovered from chimney dust—smelter chimneys of refineries of lead, titanium and zinc in the U.S.A. and industrial chimneys of England. The dust of the latter is specially rich in germanium as the English coal contains a large proportion of the same.

It is to be noted that properties akin to those of germanium are also exhibited by other materials. Silicon has been extensively used as detector in the microwave region. Very recently announcement has also been made of silicon transistors.

RADIO-ELECTRONICS IN THE SERVICE OF SCIENCE

Besides providing new apparatus, instruments and techniques for research in almost every branch of science pure and applied, radio-electronics has given rise to two new branches of science, one pertaining to the starry heavens, called Radio Astronomy and the other to molecules and atomic nuclei called generally Radio Frequency Spectroscopy (or, Microwave Spectroscopy when it pertains to the molecules.)

Radio Astronomy.—The strange discovery that there are heavenly bodies which emit radio waves has opened up a new and remarkable chapter of modern astronomy. The discovery has been possible only because of the invention of various types of electronic valves, which enables one to construct radio receivers so sensitive that they can detect the faintest of radio noise. The study of the celestial radio waves has led to the discovery of hitherto unknown types of astronomical objects.

The nearest heavenly radio source is the sun. The sun steadily emits waves in the metre range (the intensity increasing with the wavelength) even when it is quiet. When disturbed, there is much stronger emission from active spots superposed on the steady emission. Emissions from the disturbed sun are in much shorter wavelength range.

Besides the sun numerous other discrete sources of radiation have been discovered in the celestial firmament. Some of these belong to our own galaxy and some are extra-galactic. One of the problems of radio astronomy is to identify these discrete sources with heavenly objects discernible with big telescopes. Of the discrete sources in our own galaxy, there is one in the constellation of Cassiopeia which is the strongest of all the heavenly radio sources. It has been identified with a hitherto unknown type of nebulous object, the nebulosity consisting of a network of gaseous filaments in violet motion (velocity −1000 to +3000 km. per sec.). How strong this radio source is, will be apparent from the fact that estimate shows that if the source were removed ten times far away, it would still appear as a strong source, though, optically it would be too faint to be seen even by the largest telescope. A similar nebulous object, though much less intense, has been observed in the constellation Puppis. Again, a source has been identified with the Crab nebula—the remnants of the supernova of 1054 A.D. Another radio source close to the strong source in Cassiopeia mentioned above has been identified with the remnants of Tycho Brahe's supernova, too faint to be observed now.

Of the extra-galactic sources, many have been identified with the normal type of galaxies observed with the telescopes. An interesting result obtained is that the radio flux from these nebulae bears a constant ratio (nearly unity) to the light flux. There are also extra-galactic sources which do not belong to the normal type of galaxies. Thus there is Cygnus A, second in intensity to the strongest galactic Casseopeia source, which appears to be two galaxies in collision. Similar abnormal galaxies have been identified with radio sources in the constellations of Centaurus, Virgo and Perseus.

The radiations from any of the types of sources mentioned above cover a wide range of wavelength from decimetre to several metres. But a source has also been found—the hydrogen clouds distributed in the interstellar space of our own galaxy—which emits 'line' radiation of wavelength 21 cm. The discovery made simultaneously by Dutch, Australian and American radio-astronomers in 1951 has opened up a new avenue of exploring the remotest parts of our galactic system. It has yielded new and fundamental information regarding the spiral structure and the rotation of our galaxy extending to distances which could never have been reached by optical means.

A natural question to ask, what is the mechanism of radio emission from the heavenly bodies? Unfortunately, no definite theory is yet available. Only surmises have been made regarding the special features of the objects, photographed with telescopes, which may be associated with the radiation process. Thus, radiation from the quiet sun is believed to be associated with the chromosphere ; that from the disturbed sun, at the time of solar activity, is associated with "the relatively dense hot coronal material infused into the solar atmosphere." For radio emissions from the numerous discrete sources—galactic and extra-galactic—the only feature common to these objects which point to the presence of some connection with the emission, is the large random and violent motions of the gases in the nebulosities.

The radio stars provide an interesting method of studying the upper regions of the ionosphere which are not accessible to study by the standard "pulse-sounding" method from the earth's surface. The radio stars are found to 'scintillate' and the scientillations have been shown to be due to irregularities in the ionosphere. The ionosphere, in fact, makes its presence felt to the radio astronomers, not only by the scintillation phenomenon but also by reflection and absorption of the radio waves emitted by the radio stars. Studies of these phenomena enable one to investigate conditions in the ionosphere which are not otherwise possible.

A few words may now be said regarding the method of studying the celestial radio sources. Two types of apparatus are in use for the purpose—

the radio telescope and the radio interferometer. The former is a suitably mounted metallic paraboloid which brings the radio waves to a focus where the receiving antenna is placed. The latter is a suitably disposed system of antenna for producing an interference pattern. Since the wavelength is of the order decimetre to metres, the focussing paraboloid has to be many metres in diameter if a reasonable degree of intensity and resolution is desired. The diametres of the smaller paraboloids in use are of the order 20 to 50 ft., while that of the largest under construction at the Jodrell Bank Station of the University of Manchester is 250 ft.

Study of the heavens by the radio method is being pursued vigorously in the U.S.A. (Naval Research Laboratory, the Universities of Ohio, Cornell, Michigan, Harvard, Carnegie Institution of Washington), Canada (National Research Council), Great Britain (Universities of Manchester and Cambridge), France, Holland and Australia (C.S.I.R.O.). It has not yet been started in India. It is perhaps not too much to hope that it will be so in the near future under the auspices of our Council of Scientific & Industrial Research. There will be no dearth of technically trained personnel.

Microwave Spectroscopy.—An atom with its electronic structure, or a molecule composed of electrified atoms can act like a receiving or transmitting aerial, that is, it can absorb electromagnetic radiation falling on it or, if suitably excited, can emit the same.* Till recently the apparatus for studying the emission and absorption phenomena had been spectrographs, the detectors of the electromagnetic radiation being photographic plates, specially prepared if necessary, for the ultraviolet, visible and the near infra-red regions, or bolometers for the far intra-red regions. No one had thought of using purely electromagnetic apparatus for the purpose, though, it was known that the wavelengths of emission or absorption due to the rotation of molecules fall within the centimetic range or those due to the spins of the nucleus lay in the radio frequency range. But this is exactly what has been accomplished thanks to the many novel radio electronic techniques developed specially in connection with the radar.

Microwave spectroscopy, though barely a decade old, has already added greatly to our knowledge of the structure of atoms and molecules. Study of the shapes and widths of the microwave spectral lines has yielded new informations on intermolecular interactions. The well known phenomena of Zeeman Effect and Stark Effect have acquired a new interest. The theories that had been developed of the phenomena can now be subjected to regorous tests. Microwave spectroscopy has also made possible more accurate determination of the many nuclear, atomic and molecular parameters, such as, magnetic and quadrupole moments of the nuclei, nuclear spin, atomic masses, inter-atomic distances, bond angles and dipole and quadrupole moments of a molecule.

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* Transitions between the electronic energy levels of an atom or a molecule give rise to emission or absorption in the visible and ultraviolet regions, the effects of vibration and rotation of the molecule being observed as perturbation effects. Transitions between vibrational energy levels may also be measured directly in the infra-red region, the rotational effects appearing as perturbations of the same. The spectral regions involved in the above are studied by optical methods. Absorption spectra due to rotation are now studied directly in microwave spectroscopy, the nuclear effects appearing as pertubation. Finally, nuclear effects can be observed directly in the radio frequency region. It is to be noted there are also a few very special cases in which electronic energy-level differences in an atom are associated with microwave spectrum. The best known example of this is that due to the so-called Lamb-Retherford shift in the spectrum of hydrogen atom.

Microwave spectroscopy will also have many industrial applications. Of these the most extensive one will perhaps be the quantitative and qualitative analysis of chemical compounds and of isotopes.

RADIO-ELECTRONICS INDUSTRY IN INDIA

Radio-electronics industry is one of the fastest growing industries of the world. In the U.S.A. it is said to be a 9 billion dollar industry. Every important country in the west has its own radio-electronics industry, specially because of its vital importance to national defence. In India the industry is only in the stage of assembly of home receiving sets with imported components. There are about 200 small scale assemblers and 18 registered large assembling factories. And, almost all these concerns draw their designs from abroad. Radio industry proper in India is thus in an extremely backward state. This is undesirable not only because we have to spend large amounts of foreign currencies for import of receivers, component parts and valves, but also from the point of view of national defence. In case of any international complication our position would be very insecure. It is, therefore, urgent that steps be taken to establish full-fledged radio and electronics industry in the country at an early date. Two questions naturally arise in this connection : Firstly, whether the basic materials as are necessary for the industry are available in the country and secondly, whether the demands for the equipment and components produced would be large enough for economic production. In regard to the first, it is to be noted that no country can be completely self-supporting in regard to any industry. For the case of radio and electronics industry in India a survey was made some time ago of the availability of basic materials in the country. The survey, unfortunately, revealed that only about 25% of the basic materials is available. The survey was naturally concerned with the needs for radio sets for civilian use. For specialised and high quality equipment for communication, defence and industrial purposes the specifications are more stringent and hence the availability of basic materials becomes still further restricted. However, the situation is not as hopeless as it appears to be at first sight. With our programme of industrialisation, many of the basic materials may soon be expected to become available, and many others may be made available if some of the existing industries are induced to undertake manufacture of these material, which they are, at present, reluctant to do on account of small demands (*e.g.* magnet steel).

Regarding the sufficiency of demand of radio equipment and components it may be said that the Government Departments alone would import annually radio goods worth about 4 crores of rupees. The components and valves which go into the production of radio goods of this value may be estimated to be 2·4 crores of rupees. One is therefore tempted to conclude that economic manufacture of radio components and valves, which is the first step in the establishment of a radio industry, is possible in the country. Unfortunately, the components are many and varied so that the total number of any individual type may not be sufficiently large for economic mass production. The same remark applies to valves which are imported to the extent of about 2 million in number worth about 40 lacs of rupees.

(This excludes transmitting and industrial types of valves.) There are hundreds of types of valves in use imported from all over the world. The types become still further varied if we consider the valves used in communication equipment and radar systems which we import. These employ miniature and subminiature valves in addition to the normal receiving valves. However, radio receivers may be adapted to the use of such miniature valves, because, they are not more costly than ordinary valves and are capable of performing the same functions. Bearing this in mind it may be possible to standardise the valves to as low as 20 preferred types which would enable various designs of radio receivers to be made with these valves. Hence, the requirement of a particular type of valve would be high enough for economic production with a semi-automatic plant. It is to be noted that high power transmitting tubes employ manual construction and as such the economic figure is considerably lower. It would be in the region of about 500 for valves 500 watts and above. *

A beginning has already been made in India for production of radio valves with the establishment of Messrs. Bharat Electronics Limited at Jalahalli, Bangalore.[3] The well known French firm Compagnie Générale de Télégraphie sans Fil has been appointed technical consultant of the Bharat Electronics. The factory is expected to commence production of miniature valves in the latter half of 1956. It will also undertake the production of components not manufactured by the private sectors, the ultimate objective being manufacture of complete radio communication equipment including radar worth about Rs. 4 crores every year for the different Government Departments. The civilian needs appear to have been left out of consideration till now. It is, therefore, suggested that the establishment of radio industries for supplying such needs may be taken up in the Second Five Year Plan.

CONCLUDING REMARKS

Research and Training

In closing my address let me briefly refer to the position of India in regard to research and training in radio and electronics. The position in regard to industries I have just described. We are happy that steps have been taken for the establishment of state controlled industry which is to supply our vital national needs. In speaking of the position in regard to organisations of research and training, I hope to be excused if I am in a reminiscent mood.

Many years ago—in the twenties—when, as a result of lessons learnt from World War I, the western countries were organising study and research in radio and electronics, two European institutions established for the purpose greatly appealed to me. These were, the Radio Research Board of England and the Heinrich Hertz High Frequency Research Institute of Germany. I often wished that institutions like these were established in India The former of these was a government sponsored body, the main object of which was to provide a liaison between results of funda-

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*** The figures and data for this section are taken from a note kindly supplied by Messrs. Bharat Electronics Limited.**

mental research carried out in the universities (many of these under the auspices of the Radio Research Board itself) and the many developmental problems faced by the radio industries. The latter was a semi-government institution carrying on both fundamental and applied researches on radio. Knowing the policy of the then government I had, of course, no illusion as to what the fate of a proposal for the establishment of such organisations in India would be, coming specially from an insignificant individual like myself. Nevertheless, I always used to conduct a little propaganda whenever an opportunity presented itself in support of my pet ideas with the hope that this would perhaps produce some effect.

Thus, in 1935 when I had occasion to visit the U.K. I got together a number of distinguished British men of science for discussing the advisability of establishing in India a body like the Radio Research Board of England. Speeches delivered during the discussion, all in favour of its establishment, were reported in India. The late Sir Richard Gregory, Editor of Nature, who was one of the guests present at the party, was good enough to write an editorial in *Nature** supporting the idea. When, therefore, I returned to India, some months later, I was very hopeful that perhaps the opinions expressed by the very distinguished men of science would have some effect. But I was sadly disappointed. When I approached responsible authorities I was told that research on radio, or for the matter of that any scientific research of an applied character, could best be carried out in research centres in England and the results, as occasion arose, communicated to India. However, my dream was fulfilled six years later, when, in 1942, the newly formed Council of Scientific and Industrial Research, inaugurated the Radio Research Committee. The Radio Research Committee is now one of the most important Research Committees of the C.S.I.R. It must, however, be said that considering the very wide range of problems to be tackled and the number of schemes sponsored the amount of grant available is extremely inadequate. This should be increased at least tenfold to keep pace with the rapid advance that is being made in other countries.

Regarding the establishment of an independent institute for researches on radio and electronics I had always, when I was Chairman of the Radio Research Committee, tried to impress upon my colleagues the need of it. In 1945, in fact, the Radio Research Committee did actually submit a preliminary plan for the establishment of such an institute. However, it was then thought that researches on radio and electronics could be better carried out in one of the specialised sections of the proposed National Physical Laboratory. I felt therefore, very happy when nine years later I found that my long cherished desire was going to be fulfilled with the laying of the foundation of the Central Electronic Engineering Research Institute at Pilani, though, I would have liked to see the Electronic Research Institute and the Electronic industrial establishment (Jalahalli) situated closer together instead of being separated by a distance of more than a thousand miles.

In regard to teaching, it is interesting to note that "Wireless" had for a long time (since 1926 in the University of Calcutta) been one of the elective subjects in the post-graduate Physics course of our universities. But, as the subject advanced rapidly along with electronics, need was felt for introducing teaching in Radio-electronics at the post-graduate level, as an independent self-contained course. This has now been made possible mainly through the support of the All-India Council for Technical Education. (Support now transferred to the University Grants Commission.) Teaching and research in Advanced Electronics will also be organised in certain institutions with the help of special grants made by the U. G. C. These are good beginnings. It may be confidently hoped that the younger generation will now find better opportunities for acquiring knowledge of and for research in this subject of national importance.

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* *Nature*, Vol. 137, p. 841 (1936). For a report of the discussion meeting see *Science and Culture*, Vol. 1, pp. 755-58 (1935-36).

I may, therefore, conclude my address with an optimistic note. The hopes that I had cherished in my younger days regarding developments of research, training and industry in radio and electronics in our country are on their way to fulfilment. I now only wish that the developments proceed at a faster pace to meet the fast growing demand of trained men on the one hand, and of the various radio and electronic equipment on the other, for meeting civil, industrial and defence requirements.

SECTION OF MATHEMATICS

PRESIDENT: DR. B. R. SETH, M.A.,M.Sc.,Ph.D.,D.Sc. (Lond).

Presidential Address

NON-LINEAR CONTINUUM MECHANICS

1. INTRODUCTION

For more than a century, which may be called the linear era, some of the best investigators devoted their whole attention to linearizing the mathematical formulation of physical problems. The well known equations of Poisson, Laplace, the wave equation and the heat conduction equation have been fruitfully utilized in all branches of scientific activity and have contributed to the discovery and study of a number of new functions. Linearization has all the advantages of existence, uniqueness and stability. Unfortunately such is not the case with non-linear problems which have now assumed importance in all branches of scientific research. A natural phenomenon is seldom the result of linearised superposed effects. Any event is the result of a number of others dovetailing into one another, and hence any attempt at the exact formulation of a physical problem produces non-linearity in our equations.

Hardly any serious attempt, except in the case of simple vibrational equations and some elastic problems, has been made to find out what the data and stipulations are which correspond to physical reality and ensure uniqueness and stability of non-linear solutions. The method of perturbations gives higher order approximations whose convergence cannot always be proved. A classical solution need not be the first term in a power series solution of the general equation, and hence the assumption of linear solutions as the first approximation vitiates the basis of discovering new solutions. Again, large non-linear deformations may bring in both the plastic and the anistropic effects, thus making the problem even more complicated.

Despite all these difficulties a lot of research work has been published on non-linear problems in subjects like elasticity, fluid mechanics and vibrations. All the modern tools like tensor calculus, matrix algebra and topology have been used. The first symposium in Applied Mathematics of the American Mathematical Society, held at Brown University, U.S.A. in 1947, dealt with such problems. Two new effects, the Kelvin and the Póynting effécts, which cannot be given by the classical linear theory, have been discovered. These confirm the experimental facts that, to shear a block, besides shearing forces, suitable normal forces are also required.

It will be too much to expect that any non-linear theory can give all known results in the quantitative sense. One should be satisfied if it gives good qualitative results, not given by the linear theory, and good quantitative results when only comparative ratios are required. In practice a suitable approximation which should not amount to the linear theory, should be made so that it exhibits qualitatively the non-linear effects. For quantitative results the laws so found may be generalized and the constants fitted in, consistent with experimental results. This method is illustrated in Section 4.

It is impossible to give an exhaustive account of even one non-linear topic in the present address. In making a choice the personal equation of the author comes in. The problems in which a worker and his friends have taken interest for over fifteen year come foremost to his mind, and hence it is possible some important problems may not find place in this survey.

2. NATURE OF NON-LINEAR PROBLEMS

In any isothermal problem of continuum mechanics of isotropic media the distortion of the medium has to be mathematically specified. The general continuous deformation can be treated in various ways. It is produced by body forces, boundary tractions and boundary displacements, and its description requires the knowledges of the stress tensor $t^i_{\,j}$ at any point. The stress tensor satisfies the body stress equations.

$$t^{ij}_{,j} + \rho F^i = \rho \frac{Du^i}{Dt}, \tag{2.1}$$

where F^i is the force vector, u^i is the deformation vector, and

$$\frac{Du^i}{Dt} = \frac{\partial u^i}{\partial t} + u^j u^i_{,j}. \tag{2.2}$$

To determine u^i we must know e^i_j, the strain or strain velocity produced and the stress-strain relations. Non-linearity can therefore arise from any of the following causes :

(a) Body stress equations.
(b) Boundary conditions.
(c) Strain components.
(d) Stress-strain relations.
(e) Co-efficients of the medium.

Linearization of the body stress equations has given rise to classical theories like that of elasticity and slow viscous flow. Exact solutions of simple cases like that of a sphere moving through a viscous liquid do not exist. One approach, which has yielded some results, has been developed by B. R. Seth (14,15) and his co-workers. They treat the actual problem as the limiting case of an extended problem in which the body-stress equations can be exactly solved. This synthetic method has revealed the existence of semi-empirical theories like that of Prandtle's boundary layer theory.

Non-linear boundary conditions have not received much attention. Problems of wave motion in water with a free surface come under this category due to the non-linearity of the free surface conditions. This has been extensively dealt with by J. J. Stoker(81).

The small strain or strain-velocity tensor is

$$2e_{ij}=u_{i,j}+u_{j,i}. \tag{2.3}$$

The finite strain tensor referred to stressed and unstressed states respectively is given by

$$2e_{ij}=u_{i,j}+u_{j,i}-u_{k,i}\,u_{k,j}, \tag{2.4}$$

$$2\varepsilon_{ij}=u_{i,j}+u_{j,i}+u_{k,i}\,u_{k,j}. \tag{2.5}$$

Classical elastic theory uses (2.3). In the non-linear cases (2.4) or (2.5) is used. This has been the subject of a number of investigations. In 1935 a paper by B. R. Seth marked the beginning of a series of papers on this subject by a host of workers, including F. D. Murnaghan(17) and C. Truesdel.(52) in America, W. M. Shepherd(2), R. S. Rivlin(39,) K. H. Swainger(17), A.E. Green(53) in England, R. Kappus(93) in Germany, D. Panov,(94), P. M. Riz(96) and N. V. Zvolinsky(95) in Russia and A. Signorini(37) in Italy. In it the idea was stressed that for large deformations finite components of strain should be used, and that these components, like the classical boundary conditions and body stress equations, should be referred to the deformed framework, as given in (2.4).

In a linear theory the strain energy is a quadratic in the strain invariants. W. Voigt(98) was the first to propose that even when the small strain components given in (2.3) are used, the theory may be extended by taking third degree terms in the strain energy. Recently E. Sternberg(96) has pursued this idea. But it implies the coexistence of infinitesimal displacements and infinitesimal gradients such that their second and higher powers are neglected. The inclusion of the third degree terms in the strain energy therefore cannot serve any useful purpose.

In 1937 F. D. Murnaghan1(7) combined the two ideas of the finite strain components and the retention of the higher degree terms in the strain energy function. By adjusting the constants in his formula for hydrostatic pressure he finds good agreement with compressibility experiments even for pressures of 20,000 atmospheres. M. Reiner has obtained the Kelvin and Poynting effects in fluid flow by retaining the second order terms in the stress-strain velocity relations. R. S. Rivlin(30) shows that for incompressible bodies very general forms of the strain energy function can be successfully used. He has obtained some exact solutions of the general equations for incompressible bodies.

Non-Linearity due to the co-efficients of the medium arise in problems like that of turbulence and compressible flow.

K. H. Swainger(17) believes that no extension of the strain energy is required for large rotations due to finite deformation and that the second order terms in the strain components are also not necessary. He treats such problem by referring the small strains in the deformed body to a frame oriented so that an arbitrarily selected particle has suffered no rotation. This has been criticized by C. Trusedell(52) and others.

In what follows we shall confine our attention to problems arising out of (a), (c) and (d).

3. NON-LINEAR ELASTIC DEFORMATION.

In the classical theory of elasticity the strain components are assumed to be small and hence stress can be taken to be linearly connected with strain by Hooke's law. It is also immaterial whether the strains are referred to the unstrained frame or the strained frame. For finite deformation we have to make a choice, and as already pointed out, for technical applications the deformed frame should be taken. In all what follows we shall assume (x,y,z) to be the coordinates of a point in the deformed body. The corresponding strain tensor is given by (2.4). It must satisfy the consistency equations, which are obtained from the condition that the corresponding Riemann tensor must vanish identically.(7),(52).

For isotropic elastic bodies the strain energy $\rho_0 W$, is a function of the strain invariants I_1, I_2 and I_3. Following Murnaghan(17) the stress-strain relations are

$$t^i_j = \rho\left(\delta^i_k - 2e^i_k \frac{\partial W}{\partial e^j_k}\right), \tag{3.1}$$

where the densities ρ_0 and ρ, before and after strain, are given by

$$\frac{\rho}{\rho_0} = (1-2I_1+4I_2-I_3)^{\frac{1}{2}}. \tag{3.2}$$

If we put

$$2e^i_j = \delta^i_j - c^i_j \; ; \qquad h^i_j = -\tfrac{1}{2}\log c^i_j, \tag{3.3}$$

the relation (3.1) can be put in the form (52)

$$t^i_j = \rho\,\frac{\partial W}{\partial h^j_i}. \tag{3.4}$$

These can be put into the following more explicit form due to Finger(97)'(98)

$$t^i_j = 2\rho\left[\left\{I_2^{-1}\frac{\partial W}{\partial I_2^{-1}} + I_3^{-1}\frac{\partial W}{\partial I_3^{-1}}\right\}\delta^i_j\right.$$

$$\left. - \frac{\partial W}{\partial I_1^{-1}}\left(c^{-1}\right)^i_j - I_3^{-1}\frac{\partial W}{\partial I_2^{-1}}\, c^i_j\right]. \tag{3.5}$$

For incompressible bodies $I_3^{-1}=1$, and adding an arbitrary hydrostatic pressure $p\delta^i_j$, we get Rivlin's formula(39)

$$\frac{1}{\rho_0}t^i_j = -p\delta^i_j + 2\frac{\partial W}{\partial I_1^{-1}}\left(c^{-1}\right)^i_j - 2\frac{\partial W}{\partial I_2^{-1}}\, c^i_j \tag{3.6}$$

If, as has been done by Murnaghan(17), only terms up to the third degree are retained in $\rho_0 W$ we have

$$\rho_0 W = \tfrac{1}{2}(\lambda+2\mu)I_1^2 - 2\mu I_2 + lI_1^3 + mI_1I_2 + nI_3, \tag{3.7}$$

l, m, n being three new elastic constants. The corresponding stress-strain relations are

$$\begin{aligned} t^i_j = {} & [\lambda I_1 + (3l+m-\lambda)I_1^2 + mI_2]\delta^i_j \\ & + [2\mu - (m+2\lambda+2\mu)I_1]e^i_j \\ & - 4\mu e^i_\alpha e^\alpha_j + nI_3(e^{-1})^i_j, \end{aligned} \tag{3.8}$$

where

$$I_3(e^{-1})^i_j = \frac{\partial I_3}{\partial e^j_i}\,.$$

If all the new elastic constants l, m, n can be neglected, these take the following simple forms in cartesian coordinates :

$$t_{xx} = \lambda I_1(1-I_1) + 2[\mu-(\lambda+\mu)I_1]e_{xx} - 4\mu(e_{xx}^2 + e_{xy}^2 + e_{xz}^2), \tag{3.9}$$

$$t_{xy} = 2[\mu-(\lambda+\mu)I_1]e_{xy} - 4\mu(e_{xx}e_{xy} + e_{xy}e_{yy} + e_{xz}e_{yz}). \tag{3.10}$$

Signorini(34) has shown that in order that the stress tensor be exactly a quadratic function of the strain tensor the strain energy is of the form.

$$\rho_0 W = \frac{\mu(1-I_1) + \frac{1}{2}(\lambda+\mu)I_1^2}{\sqrt{1-2I_1+4I_2+8I_3}} - \mu, \tag{3.11}$$

the corresponding stress-strain relations being

$$t^i_j = [\lambda I_1 + \tfrac{1}{2}(\lambda+\mu)I_1^2]\delta^i_j + [2\mu-(\lambda+\mu)I_1]e^i_j. \tag{3.12}$$

$\rho_0 W$ is to be positive and the necessary and sufficient conditions are $e_i \leqslant \frac{1}{2}$, $\mu > 0$, $-\frac{5}{8} \leqslant \sigma \leqslant \frac{1}{2}$, σ being the Poisson's ratio.

From the stress-strain relations given above it is obvious that the non-linear problem even for isotropic elastic bodies is not easily tractable. For incompressible bodies the simplicity of the relations (3.6) have enabled Rivlin to obtain some excellent general solutions for any form of the strain energy function. But for compressible bodies which are of importance in all technical applications no general solutions except for homogeneous strain have yet been found. In all such cases the form of the strain energy function has to be assumed.

For most structural materials, even in the largest purely elastic deformation the strain is small, though the displacement gradients and rotation may be large. For such cases the second degree terms in the stress-strain relation (3.1) may be neglected. This approximation gives the following relations used by Seth in a large number of applications :

$$t^i_j = \lambda\, I_1\, \delta^i_j + 2\mu\, e^i_j. \tag{3.13}$$

Synge and Chien(103) have also used these relations in the finite deformation of plates and shells.

As has been already stated, no theory, however exact, can be expected to give all the non-linear results. In fact even the Mooney-Rivlin theory for incompressible bodies like rubber gives a tension-stretch law which does not suggest a yield point.

For actual applications it is therefore desirable to have a stress-strain law which can be extensively used, and for this purpose (3.13) is found to be the most suitable. Even Signorini's exact quadratic relations exhibit the same general results as obtained by Seth in simple cases of tension, shear and hydrostatic pressure. It is true that Rivlin's general results for incompressible bodies show that for simple shear two of the normal stresses need not be equal, as in the solutions obtained by Seth or Signorini, but this is hardly expected to occur in practice.

We shall now give some applications, using the relations (3.13). The results thus obtained will be compared with those obtained by Rivlin, Signorini, Green and others.

4. SIMPLE EXTENSION

In this case the strain is homogeneous and the deformation matrix can be written in the form $x=AX$, A being a constant matrix. The strain and stress tensors are constants and the equations of equilibrium are identically satisfied. The stress-strain relations (3.13) give the displacements as

$$\begin{aligned} u &= x[1-(1+2\sigma T/E)^{\frac{1}{2}}], \\ v &= y(1-(1+2\sigma T/E)^{\frac{1}{2}}] \\ w &= z[1-(1-2T/E)^{\frac{1}{2}}], \end{aligned} \tag{4.1}$$

σ being the Poisson's ratio, E the Young's modulus, and T the tension applied.

If s is the ordinary stretch, the tension-stretch curve is given by

$$2T=E\left[1-\frac{1}{(1+s)^2}\right]. \tag{4.2}$$

This suggests the yield point, when $s\to\infty$, at $T=\frac{1}{2}E$, and the curve is not unlike that found in many elastic materials.

Murnaghan's [17] treatment gives a parabolic law which does not give any such curve. Rivlin's [39] results for an incompressible body give

$$T=\left[1+s-\frac{1}{(1+s)^2}\right]\left[\qquad\frac{\beta}{1+s}\right. \tag{4.3}$$

where

$$E=3(\alpha+\beta)-3\mu.$$

This again does not give any qualitative description of a yield point. The general results for a compressible body can be written down from Finger's relations[35] but they can hardly be expected to give any concrete results. Signorini's[31] exact quadratic theory gives

$$T=(\lambda+\mu)\left[\frac{1+2\sigma+e-e^2}{\sqrt{1+e^2+4\sigma e}}-1-2\sigma+e\right], \tag{4.4}$$

where

$$2e=1-\frac{\qquad}{(1+s)^2}.$$

This gives a curve of the same character as given by (4.2). In both (4.3) and (4.4) T is measured per unit area of the unstrained section. Both (4.2) and (4.4) give values of the yield stress which are higher than those found in practice. As already stated such formulae should be generalised and the constants fitted in consistent with experimental results. One such generalisation can be

$$T=\left[1-\frac{1}{(1+s)^2}\right]\frac{E+Bs^2}{1+Ds^2}, \tag{4.5}$$

B and D being constants such that $B/D=Y$, the yield stress. For small values we get $T=Es$. B and D may be determined from experimental results.

The relations (4.2), (4.3), (4.4) and (4.5) all distinguish between pressure and tension, which is a non-linear effect not given by the ordinary theory. Excepting (4.3) all show that no finite force can contract the volume to zero, that is, $T\to\infty$ as $s\to-1$.

Without assuming any stress-strain relations Murnaghan[22] developes a rate of deformation theory. By building up the final configuration from a succession of infinitesimal strain by a method of integration he obtains the tension stretch curve as

$$(1+s)^{\alpha}=\frac{1+aT}{1-bT}, \tag{4.6}$$

α, a, b being constants.
This gives a yield stress $1/b$, but is defective as a finite pressure $T=-1/a$ reduces the volume to zero.

If we use the relation (4.2) in place of Hooke's law we get a number of characteristic results. For finite longitudinal vibration of strings and rods, the displacement ξ is found to satisfy the differential equation$^{(11)}$

$$\frac{\partial^2\xi}{\partial t^2}=\frac{E}{\rho}\frac{\dfrac{\partial^2\xi}{\partial x^2}}{\left(1+\dfrac{\partial\xi}{\partial x}\right)^3}. \tag{4.7}$$

This is exactly the general equation for long waves in a canal.This analogy shows that the stress-strain relation in (4.2) can be expected to give good results.

For the vertical oscillations of a mass m attached to a light elastic string the relation (4.2) gives the known result that finite oscillations are not harmonic. If l is the unstretched length, l' the stretched length in the position of equilibrium, the relation between the time t and the displacement is found to be $^{(3)}$

$$t=2\left(\frac{ml}{E}\right)^{\frac{1}{2}}\left(\frac{l'}{l}\right)^{\frac{3}{2}}(\sec\ \theta)^{\frac{1}{2}}E(k,\phi), \tag{4.8}$$

where $k=\sin\ \theta=(\alpha-\beta)/\alpha$, is the modulus of the elliptic function $E(k,\phi)$ of the second order, and α, β are the values of the vertical distance y measured from the fixed point where the velocity of m vanishes. The value of y is

$$y=\alpha\,(1-k^2\sin^2\phi), \tag{4.9}$$

and the complete period is

$$T=4\left(\frac{ml}{E}\right)^{\frac{1}{2}}\left(\frac{l'}{l}\right)^{\frac{3}{2}}(\sec\ \theta)^{\frac{1}{2}}\ E_0, \tag{4.10}$$

E_0 being the complete integral of the second kind. Thus the actual motion is not strictly simple harmonic. It is found that it does not vary much with the amplitude as long as it is not greater than $0.539l'$.

5. HYDROSTATIC PRESSURE

A treatment similar to that given in Section 4 gives the relation between pressure p and contraction s as

$$p=\frac{3}{2}k\left[\frac{1}{(1-s)^2}-1\right]=\frac{3}{2}\ \left[\left(\frac{v_0}{v}\right)^{\frac{2}{3}}-1\right], \tag{5.1}$$

k being the modulus of compression v_0 and v being the initial and final volumes.

The exact theory only gives an equation of the form $p=f(v)$. The relation (5.1) exhibits all the non-linear effects. Murnaghan takes the more general formula

$$p = A\left[\left(\frac{v_0}{v}\right)^{\alpha} - 1\right], \tag{5.2}$$

where α and A are adjusted consistent with experimental results. But this is only a generalisation from (5.1). He obtains good agreement with Bridgeman's experiments on the compression of sodium up to 100,000 atmospheres(175). This again shows, that the results obtained from the stress-strain relations given in (3.13) can be generalised and used profitably.

6. SIMPLE SHEAR

It is in simple shear that we get the two important non-linear effects, the Kelvin effect and the Poynting effect. In this case the deformation is given by $x=AX$, where

$$A = \begin{bmatrix} 1 & K & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

The stress-strain relations (3.13) give

$$t = -\tfrac{1}{2}\lambda K^2 \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} + \mu K \begin{bmatrix} 0 & 1 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} \quad \mu K^2 \begin{bmatrix} 0 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0 \end{bmatrix} \tag{6.1}$$

This agrees with Signorini's(34) results obtained with the help of (3.11) up to the second degree terms in K. It also proves the existence of normal stress effects, called the Kelvin and Poynting effects. In the Kelvin effect the body changes in volume, if a hydrostatic tension proportional to K^2 is not applied. In the Poynting effect its proportions change, if normal tractions proportional to K^2 are not applied. Rivlin's general theory gives an extra term of the type

$$K^2 \begin{bmatrix} 1 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} \tag{6.2}$$

which shows that t_x^x need not be equal to t_z^z, as is given by (6,1)

7. PURE FLEXURE.

Seth(1) was the first to get the Poynting effect for bending. He showed that in order to produce pure bending of a rectangular block with curved faces free from traction, suitable normal tractions on the faces parallel to the plane of bending must be applied. He discussed in detail the case of a thick plate bent by terminal couples. The components of displacement taken by him are

$$u = x - f(r), \quad v = y - A\theta, \quad w = \alpha z. \tag{7.1}$$

These have been used by Signorini(31), Rivlin(39), Green (58) and others. Seth and Signorini both show that for any prescribed angle of flexure and change of altitude the solution is unique Seth's solution gives

$$\frac{df}{dr} = \left(\frac{l}{r^c} - \frac{A^2}{r^2}\right)^{\frac{1}{2}}, \quad c = \frac{1-2\sigma}{1-\sigma}, \tag{7.2}$$

$$A^2 = \frac{(2-c)(ab)^{2-c}(a^c - b^c)}{c(a^{2-c} - b^{2-c})}, \quad l = \frac{(2-c)(a^2-b^2)}{a^{2-c} - b^{2-c}} \tag{7.3}$$

a and b being the internal and the external radii.

The unstretched longitudinal plane is $r = A$, which is also the result obtained by Rivlin. It is not the plane given by the infinitesimal theory. The couples to be applied to the straight and curved edges are found to be

$$M_1 = \mu\left[\frac{1}{2}(b^2 - a^2) - \frac{(2-c)\log(b/a)(ab)^{2-c}(a^c - b^c)}{c(a^{2-c} - b^{2-c})}\right], \tag{7.4}$$

$$M_2 = -\lambda\left[\frac{1}{3}(b^3 - a^3) - \frac{1}{2}\cdot\frac{2-c}{3-c}\cdot(a^2 - b^2)\cdot\frac{a^{3-c} - b^{3-c}}{a^{2-c} - b^{2-c}}\right]. \tag{7.5}$$

These reduce to the known values D/a and $\sigma D/a$ for a thin plate of thickness h, where the rigidity D is given by

$$D = \frac{1}{6}\mu(2-c)h^3.$$

For an incompressible block Rivlin finds that in terms of the strain energy function W, the couple M, applied to the straight edges is

$$M_1 = \frac{1}{2}(b^2 - a^2)(W)_{r=a} - \int_a^b rW\,dr. \tag{7.6}$$

The result obtained in (7.4) may be used to discuss large deflections of cantilever beams. Many workers have discussed this problem without using the extended bending moment formula given in (7.4) (74)(100)(107)(116).

Let P be the concentrated load at the free end and $\rho=ds/d\theta$, the radius of curvature. If $\theta=\theta_0$ at the free end where $\rho=0$, the equation to find ρ at any point, when (7.4) is used, is found to be given by

$$(2-6c+c^2)\frac{h^2}{\rho^4}-\frac{10}{\rho^2}+20\frac{P}{D}(\sin\theta-\sin\theta_0)=0, \tag{7.7}$$

the new value of the bending couple being

$$M_1=\frac{D}{\rho}\left[1+\frac{1}{12}(2-6c+c^2)\frac{h^2}{\rho^2}\right].$$

If h^2/ρ^4 is neglected, we get the known equation

$$\frac{1}{\rho^2}=\frac{2P}{D}(\sin\theta-\sin\theta_0). \tag{7.8}$$

In (7.7) the thickness is taken as $2h$ in place of h used in (7.4).

8. TORSION OF CYLINDERS.

By using displacements corresponding to a finite twist Seth(1) has shown that normal stresses must be applied to the plane ends of a twisted cylinder in order to keep the curved surface free from traction. This Poynting effect has also recently been obtained by Rivlin(39), Green and Shield(55), Kappus(83) and Riz(87). Most of them do not use finite components of displacements as used by Seth.

Panov(81) treats the case of an elliptic cylinder and obtains the same result for small angles of twist. Green and Shields (56) solve the problem for a small twist of a prism of arbitrary isotropic elastic materials subject to biaxial extension. But this does not hold good for a large twist and hence the advantage gained in taking an arbitary strain energy function W at the expense of finite twist is vitiated. Similar remarks apply to Rivlin's solution for an incompressible cylinder.

For a large torsional shift, α, Saint-Venant gives the components of displacement as

$$\begin{aligned} u&=-y\sin\alpha z+x(1-\cos\alpha z),\\ v&=x\sin\alpha z+y(1-\cos\alpha z),\\ w&=\alpha\phi(x,y). \end{aligned} \tag{8.1}$$

These assume that there is no radial displacement in a section of the cylinder.

For a finite twist in a circular cylinder, a radial displacement should be assumed, and then the components of displacement become

$$\begin{aligned} u &= y\beta \sin \alpha z + x(1-\beta \cos \alpha z), \\ v &= x\beta \sin \alpha z + y(1-\beta \cos \alpha z), \\ w &= \alpha z, \end{aligned} \tag{8.2}$$

β being a function of r ($r^2 = x^2 + y^2$) only.

The body stress-equations are all satisfied if β satisfies the differential equation.

$$(1+t)\beta^2 + \left(2t\frac{d\beta}{dt} + \beta\right)^2 + 2c\int t\left(\frac{d\beta}{dt}\right)^2 dt = K, \tag{8.3}$$

K being a constant, $t = (1-c)\alpha^2 r^2$ and $c = (1-2\sigma)/(1-\sigma)$.

Using the relations (3.13) and assuming that the resultant of the axial stresses also vanishes over the plane ends, the curved surface being free from traction, we get

$$\beta^2 = 1 - \tfrac{1}{4}(1-c)\alpha^2(r^2-a^2) - \frac{1}{6.8^2}(1-c)^2\alpha^4[r^4(12-c) - 24a^2r^2 + (8+c)r^4],$$
$$+ \dots\dots\dots\dots \tag{8.31}$$

$$d = \tfrac{1}{4}\alpha^2 a^2 + \frac{1}{96}(5-2c)\alpha^4 a^4 + $$

where a is the radius of the cylinder in the strained state. The torsional couple M is given by

$$M = \tfrac{1}{2}\mu\pi\alpha a^4\left[1 + \frac{1}{12}(1-c)\alpha^2a^2 - \frac{(1-c)^2}{12.16}(1-\tfrac{1}{4}c)\alpha^4a^4 + \dots\dots\right] \tag{8.4}$$

Riz, Panov, Rivlin, and others do not use the finite components of strain as given in (8.2). Riz uses (8.2) for a circular cylinder but assumes β to be of the form $1+\alpha^2 f(r)$ and thus cannot get any change n the torsional couple M, which is of the third degree in α. Panov uses terms only of the second degree in α for discussing the torsion of an elliptic cylinder. Rivlin takes Saint-Venant values and assumes no radial displacement. His calculations are also confined only to the second degree in α and so he also finds that M is unaltered. For $a\alpha = \pi/2$ this correction for M is as much as 6.41 per cent.

The stress components corresponding to the displacement (8.2) are found to be

$$t_{rr} = \lambda\Delta + \mu(1-\beta^2) - \mu\left(\beta'^2 + \frac{2\beta\beta'}{r}\right)r^2,$$

$$
\begin{aligned}
&t_{r\theta}=0,\\
&t_{\theta\theta}=\lambda\Delta+\mu(1-\beta^2),\\
&t_{zz}=\lambda\Delta+\mu(2d-d^2-\beta^2\alpha^2r^2),\\
&t_{\theta z}=\mu\alpha r\beta^2,\\
&t_{rz}=0,
\end{aligned}
\tag{8.5}
$$

where $\Delta=1+\beta^2+d-\frac{1}{2}d^2-\frac{1}{2}\left(\beta^2\alpha^2+\beta'^2+\frac{2\beta\beta'}{r}\right)r^2,$

$$\beta'=\frac{d\beta}{dr}.$$

If we make $\lambda\to\infty$ and $\sigma\to1/2$, so that $E=3\mu$, $c\lambda=\frac{2}{9}E$, and retain terms up to the second degree in α we get

$$
\begin{aligned}
&\lambda\Delta=\tfrac{1}{6}\alpha^2(\alpha^2-2r^2),\\
&T_{rr}=\tfrac{1}{12}E\alpha^2(\alpha^2-r^2),\\
&t_{\theta\theta}=\tfrac{1}{12}E\alpha^2(\alpha^2-r^2)-\tfrac{1}{3}E\alpha^2r^2,\\
&t_{zz}=\tfrac{1}{3}E\alpha^2(\alpha^2-2r^2),\\
&t_{\theta z}=\tfrac{1}{3}E\alpha r.
\end{aligned}
\tag{8.6}
$$

There is a serious drawback in the solutions of Kappus, Rivlin and Riz. The first two take $\beta=1$ and the third $\beta=1+\alpha^2f(r)$, and thus both of them have no arbitrary constant at their disposal to adjust the normal tractions on the plane ends. They should have taken $\beta=A_0[1+\alpha^2f(r)]$, if powers of α higher that the second are neglected. Then it is found that the statement that the torsion of the cylinder is accompanied by a varying normal traction of the type ar^2-b where a and b are known constants, acting on the plane ends, has no meanings. They can adjust the resultant traction to any desired value. In our solution we have assumed it to be zero. In his torsion solution for the elliptic cylinder, Panov introuces a constznt to satisfy the condition of no traction over the plane ends. From (8.6) we see that in our solution the unstretched longitudinal fiber is goven by $r=a/\sqrt{2}$, terms higher than α^2 being neglected.

If a_0 is the radius of the cylinder before strain, we get

$$a_0=a\left[1-\frac{1}{3.8^2}(1-c)^2\alpha^4a^4+\dots\dots\dots\right]\tag{8.7}$$

so that the change in the radius of the cylinder is of the order α^4.

The approximate results mentioned above do not give any change in a_0. Riz gets a change in a_0 of the order α^2 without satisfying the boundary condition on the plane ends. He fails to notice that we have taken the plane ends to be free from traction. If a finite value is taken for the traction on the plane ends, the change in a_0 will be of the order α^2. Again, for a first approximation, this finite value of the traction and the corresponding extension d are found from (8.5) and (8.31) to be proportional to α^2. Rivlin verifies this by experiment with a rubber cylinder(37).

9. SHELLS AND TUBES UNDER UNIFORM PRESSURE

For the symmetrical deformation of a thick spherical shell subjected to uniform internal and external pressures, we find that the radial displacement and the stress components are given by$^{(2)}$

$$u_r=(1-P)r, \tag{9.1}$$

$$t_{rr}=\tfrac{1}{2}(3\lambda+2\mu)(1-P^2)-\tfrac{1}{2}(\lambda+2\mu)P^2V(V+2), \tag{9.2}$$

$$t_{\theta\theta}=t_{\phi\phi}=\tfrac{1}{2}(3\lambda+2\mu)(1-P^2)-\tfrac{1}{2}\lambda P^2V(V+2), \tag{9.3}$$

where P is a function of $r(r^2=x^2+y^2+z^2)$ only, $V=rdP/rdr$, and the equation giving V is

$$\log r=\tfrac{1}{8}\log(V^2+2FV+3)-\tfrac{1}{2}\log V^2$$

$$-\frac{3-F}{\sqrt{3-F^2}}\tan^{-1}\left[\frac{V+F}{3\sqrt{3-F^2}}\right]+K, \tag{9.4}$$

where K is a constant of integration and $F=(\lambda+3\mu)/(\lambda+2\mu)$. Using these equations, Shepherd and Seth have discussed a number of cases which cannot be dealt with by the small-strain theory. Their results show that the stresses t_{rr} and $t_{\theta\theta}$ should satisfy the inequality

$$-\frac{1-2\sigma}{1-\sigma}<\frac{2(t_{rr}-t_{\theta\theta})}{3\lambda+2\mu-2t_{rr}}<\frac{1-2\sigma}{2\sigma}. \tag{9.5}$$

Similar results have been obtained for a circular cylindrical tube. They get

$$u_r=(1-Q)r, \tag{9.6}$$

$$w=\alpha z, \tag{9.7}$$

$$t_{rr}=\lambda\Delta+\mu[1-Q^2(U+1)^2], \tag{9.8}$$

$$t_{\theta\theta}=\lambda\Delta+\mu(1-Q^2), \tag{9.9}$$

$$t_{zz}=\lambda\Delta+\mu[1-(\alpha-1)^2], \tag{9.10}$$

where

$$\Delta=\tfrac{1}{2}[3-(\alpha-1)^2-Q^2\{1+(U+1)^2\}],\quad \frac{r}{Q}\frac{dQ}{dr}=U,$$

and

$$\log r=\tfrac{1}{2}\log(U^2+2GU+2)-\tfrac{1}{4}\log U^2$$

$$-\frac{2-G}{2\sqrt{2-G^2}}\tan^{-1}\left(\frac{U+G}{\sqrt{2-G^2}}\right)+K, \tag{9.11}$$

where $G=(2\lambda+5\mu)/2(\lambda+2\mu)$. The inequality corresponding to (9.5) is

$$-\frac{1-2\sigma}{1-\sigma}<\frac{t_{rr}-t_{\theta\theta}}{\lambda+\mu-t_{rr}}<\frac{1-2\sigma}{\sigma}. \tag{9.12}$$

If r' is the value of r in the unstrained state, we get $dr'/dr = Q(1+U)$, which is negative if $U<1$. Putting $\sigma = 0.49$ they have discussed the case of an India rubber tube turned inside out with its plane ends and curved boundary free from traction. They find that the percentage increase in the external radius of the tube is about 3 per cent, and this is approximately verified by experiment.

10. ELASTIC FAILURE

The limitations imposed on ths stress components by the inequalities given in (9.5) and (9.12) give rise to an important criterion of elastic failure.(5) According to the maximum stress hypothesis

$$p_1 - p_3 = k, \text{ (const.)} \tag{10.1}$$

where the principal stresses p_1, p_2, p_3, are in descending order of magnitude. Putting $p_3 = 0$ and then $p_1 = -p_2$ we get the ratio between the yield point in shear and the yield point in tension as

$$\xi = 0.5. \tag{10.2}$$

Von Mises-Hencky hypothesis for elastic failure can be written as

$$(p_1 - p_2)^2 + (p_2 - p_3)^2 + (p_3 - p_1)^2 = K, \tag{10.3}$$

and proceeding as above, we get

$$\xi = 0.577. \tag{10.4}$$

A feature common to all such theories of elastic faliure is that the criterion of failure is unaltered by a reversal of the sign of stress. But it is well known that materials show yield stresses in compression several times those in tension. Again, the values of ξ in (10.2), (10.4) do not depend upon the elastic constants. In actual practice, they always depend upon σ. The inequalities in (9.5) and (9.12) give a criterion which does away with these drawbacks and contains in itself the two rival hypotheses of elastic failure.

Taking the upper limit, we get for extension

$$p_1 - p_3 + \tfrac{1}{2}\,\frac{1-2\sigma}{1+\sigma}\,(p_1 + p_2 + p_3) = \tfrac{3}{4}\,\frac{E}{1+\sigma}. \tag{10.5}$$

If p and s are the yield stresses in tension and shear, we get

$$p = \tfrac{1}{2}E, \quad s = \tfrac{3}{8}\cdot\frac{E}{1+\sigma}, \tag{10.6}$$

and hence

$$\xi = \frac{3}{4}\cdot\frac{1}{1+\sigma}. \tag{10.7}$$

Most of the materials with which common experiments are done have σ varying between 0.25 and 0.3. In such cases, we get

$$0.577 < \xi < 0.6, \tag{10.8}$$

which is in very good agreement with tensile tests.

For contraction, we easily get

$$\xi = \frac{3}{2} \cdot \frac{\sigma}{1+\sigma}, \tag{10.9}$$

and, for $0.25 < \sigma < 0.3$, we have $0.3 < \xi < 0.346$.

From (9.12), assuming that $t_{rr} - t_{zz}$ is the maximum principal stress difference, we get for tension

$$p = \frac{E}{2(1+\sigma)}, \quad s = \frac{E}{4(1+\sigma)}, \quad \xi = 0.5, \tag{10.10}$$

and for contraction

$$p = \frac{E(1-\sigma)}{6\sigma^2}, \quad s = \frac{E(1-\sigma)}{4\sigma(1+\sigma)}, \quad \xi = \frac{3\sigma}{2(1+\sigma)}. \tag{10.11}$$

Thus, if k is the ratio of yield stress in compression to yield stress in tension,

$$K = \frac{1-\sigma^2}{3\sigma^2}. \tag{10.12}$$

For concrete $\sigma = 0.2$, and we get $r = 8$ which is in good agreement with experimental results. Thus we see that in all cases the criterion of failure can be written as

$$p_1 - p_3 + c(p_1 + p_2 + p_3) = k, \tag{10.13}$$

where c and k are suitable constants. This is similar to that suggested by J. J. Guest with this difference that he uses only $p_1 + p_3$ and not the average volumetric stress. Guest says that the form (10.13) is found to be suitable even for (*i*) combined stress and (*ii*) anisotropic materials.

11. MISCELLANEOUS PROBLEMS

In two papers Seth (8) has discussed the following problems of finite strain pertaining to nonisotropic elastic bodies : (1) simple tension (2) hydrostatic pressure, (3) pure cylindrical flexure of a rectangular plate, (4) torsion of a right circular cylinder, and (5) symmetrical strain in shells and tubes under uniform pressure.

In the case of simple tension, shear is also produced unless the cylinder possesses three orthogonal planes of symmetry. Two sets of values for the components of displacement have been obtained and, it is possible, one of them may correspond to aeolotropic materials like pyrites which expand slightly in a lateral direction when extended in the direction of a principal axis.

In pure cylindrical flexure, the plate is assumed to be transversely isotropic.

The stretching, bending, and torsion of bars, composed of different materials having the same Poisson ratio but different elastic moduli, have been discussed by Gorgidze and Ruchadze.(109). L. M. Milne-Thomspon(118) has also discussed finite deformation in aeolotropic bodies.

In a recent paper Ericksen and Rivlin(48) have discussed large elastic deformations of homogeneous anisotropic materials which are transversely isotropic.

For incompressible bodies subjected to combined loads A. E. Green[131] and others have obtained general results. They have used the perturbation method to solve problems in which a finite deformation is combined with a small torsion.

Seth(6) has also discussed the finite strain in a rotating shaft. He discusses the two cases when (1) the length of the cylinder is maintained constant and (2) the resultant longitudinal tension vanishes over the plane ends. He takes the particular case when the angular velocity ω is connected with the elastic constants by the relation

$$\rho a^2\omega^2 = \frac{\mu(2-c)(10+c)}{c(5-c)}, \tag{11.1}$$

ρ being the density, a the strained radius, and $c=(1-2\sigma)/(1-\sigma)$. Comparing his results with those given by the small-strain theory, he finds that the difference between them can be as much as 10 per cent.

S. T. Newing and W. M. Shepherd(129) have discused finite strain dislocation solutions and have obtained a number of interesting results. In particular, they obtain numerical results for a plate of constant initial curvature, bent by edge couples so that its curvature is either increased or decreased. They find that the couple required to produce a given decrease in curvature is less than that calculated from the small-strain theory.

The case of a spherical shell turned inside out has been discussed by Seth(4). He finds that the increase in its external radius is about 2 per cent.

The following problems concerning incompressible cylinders and spheres have also been treated by Seth(4) : (1) symmetrical bending of cylinders acted upon by a body force, with special reference to a rotating shaft and (2) a sphere acted upon by a body force, with special reference to a gravitating sphere.

P P. Chatterjee (130) has discussed finite strain in the interior of the earth and has obtained a number of numerical results.

12. NON-LINEAR FLUID DYNAMICS: STOKESIAN FLUID

Irrotational problems of perfect fluid flow can be linearised and hence they have been the subject of a large number of investigations. A number of axially symmetric rotational flows can also be treated as linear problems. (125, 127, 128) Slow viscous flow is also linear in character. For finite Reynold's numbers non-linear solution of Navier-Stokes equations have to be obtained. For a Stokesian fluid the stress-strain velocity tensor relation is the same as given in (3.13), with the difference that u^i is now the velocity vector.

Most of the non-linear problems are the result of what are called boundary or edge effects. Their general solution is almost an impossible task. They are therefore subjected to a simplifying process so that they narrow down to the investigation of a particular aspect of an event. An over-all picture is not obtained and a number of important effects remain unknown.

All analytical solutions are limiting cases of the actual state of a phenomenon. The limiting state can be approached in an infinite number of ways. The reducing method has been very much in fashion. It has not been generally appreciated that it is possible that, instead of narrowing down a field, its extension might give exact solutions of nonlinear problems. Such a method used by Seth(15) and his co-workers, which may be called synthetic, not only gives known solutions as limiting cases, but also throws light on a number of allied problems.

When applied to Navier-Stokes equations of viscous flow this method gives interesting results. No exact solution of the equations of motion is known even for sphere or a cylinder moving uniformly through a viscous liquid. By the introduction of an external force X in the direction of motion, an exact solution can be obtained. When X is made to approach zero we get the following results:

(1) The irrotational solution.
(2) Motion due to Hill's spherical vortex.
(3) Stokes' solution and its relationship to Oseen's solution.
(4) An expression for the drag which depends on the relative values of the viscosity, velocity, and size of the body.
(5) Prandtle's boundary layer theory.

This method can be extended to other cases and can be profitably used in allied fields of research.

13. BOUNDARY LAYER EFFECTS IN CLASSICAL HYDRODYNAMICS

It can be shown by using the synthetic method indicated in Section 12 that the semi-empirical Prandtle's boundary layer theory can be deduced from Navier-Stokes equations.

We take the case of a sphere moving uniformly through a viscous liquid. We can take the velocity components as$^{(14)}$

$$\left.\begin{aligned} u &= f(r) + x^2\phi(r), \\ v &= \phantom{f(r) + {}} xy\phi(r), \\ w &= \phantom{f(r) + {}} xz\phi(r). \end{aligned}\right\} \tag{13.1}$$

The equation of continuity gives

$$f' + 4r\phi + r^2\phi' = 0, \tag{13.2}$$

where dashes denote differentiation with respect to r. The equations of motion are

$$\rho\frac{Du^i}{Dt} = \rho F^i - \text{grad } p + \nu\Delta^2 u^i. \tag{13.3}$$

Substituting the values of u, v, w from (13.1) in (13.3) we see that all of them are satisfied if

$$-\frac{p}{\rho} + \nu x\left(\frac{f'}{r} + 9\phi + 2r\phi'\right) \quad \int rf\phi dr - x^2\int(f\phi' + 2r\phi^2 + r^2\phi\phi')dr$$

$$= \text{a constant, say } \lambda. \tag{13.4}$$

$$Y = 0, \qquad Z = 0, \tag{13.5}$$

$$X = -\frac{\nu}{r^2}\frac{d}{dr}\Big[r^2(f' - r\phi)\Big] + x\left(\frac{f}{r} + r\phi\right)(f' - r\phi) + 2x\int \phi(f' - r\phi)dr. \tag{13.6}$$

To obtain the exact solution X must also vanish. It vanishes when

$$f' = r\phi, \tag{13.7}$$

which gives the irrotational motion. It also vanishes for Hill's spherical vortex.

If we put the first term in the values of X given by (13.6) equal to zero, we get

$$\frac{d}{dr}[r^2(f' - r\phi] = 0, \tag{13.8}$$

which is Stokes' solution. But this solution makes the kinetic energy of the field infinite. To get a finite value we put

$$\rho X = -A\mu . \frac{(n-2)(n-4)}{r^{n+1}} + \rho x\psi(r). \tag{13.9}$$

This combined with (13.2) and the boundary conditions gives

$$\left.\begin{aligned} u &= \tfrac{1}{2}.\frac{n-1}{n-4}.\,U\left(\frac{a}{r}\right)^3 + \tfrac{3}{2}.\frac{n-3}{n-4}.\,U.\left(\frac{a}{r}\right)^{n-1} \\ &\qquad + \tfrac{3}{2}.\frac{n-1}{n-4}.\,U.\frac{x^2}{a^2}.\left[\left(\frac{a}{r}\right)^5 - \left(\frac{a}{r}\right)^{n+1}\right], \\ v &= \tfrac{3}{2}.\frac{n-1}{n-4}\,U.\frac{xy}{a^2}.\left[\left(\frac{a}{r}\right)^5 - \left(\frac{a}{r}\right)^{n+1}\right]. \\ w &= \tfrac{3}{2}.\frac{n-1}{n-4}.\,U.\frac{xz}{a^2}.\left[\left(\frac{a}{r}\right)^5 - \left(\frac{a}{r}\right)^{n+1}\right]. \end{aligned}\right\} \tag{13.10}$$

while X becomes

$$\begin{aligned} \rho X = -\tfrac{3}{2}.\frac{\mu U}{a^2}.(n-1)(n-2)\left(\frac{a}{r}\right)^{n+1} - \tfrac{3}{2}.\rho\frac{U^2}{a}.\frac{n-1}{n-4}.\frac{x}{a}\left[\frac{n^2-1}{n+4}\left(\frac{a}{r}\right)^{n+4}\right. \\ \left. -\tfrac{3}{2}.\frac{n+1}{n}.\left(\frac{a}{r}\right)^{2n}\right]. \end{aligned} \tag{13.11}$$

The drag D is found to be

$$D = 6\pi\mu Ua(n-1). \tag{13.12}$$

The vorticity is given by

$$\left.\begin{aligned} \xi = 0,\ \eta &= -\tfrac{3}{2}.(n-1).\frac{Uz}{a^2}.\left(\frac{a}{r}\right)^{n+1} \\ \zeta &= \tfrac{3}{2}(n-1).\frac{Uy}{a^2}.\left(\frac{a}{r}\right)^{n+1}. \end{aligned}\right\} \tag{13.13}$$

When n is large we notice from (13.1) that the velocities tend to take the irrotational values at all points not near the surface of the sphere. The corresponding values of X and the vorticity also tend to zero except at points near the surface, where they are quite large. The motion is therefore irrotational everywhere, except in a small layer near the surface of the sphere.

The manner in which the drag formulae (13.12) may be used for finite values of n has been explained in the original paper.

Similar results are obtained for the motion of a circular cylinder in a viscous liquid In this case the drag formula takes the form

$$D=4\mu\pi U(n-1). \tag{13.14}$$

H. G. Venkatesh(119) has applied this method to the motion of an ellipsoid or an elliptic cylinder through an infinite viscous liquid. He takes the velocity components as

$$\left.\begin{aligned} u&=f(\xi)+x\frac{\partial\xi}{\partial x}\lambda(\xi),\\ v&=\phantom{f(\xi)+{}}x\frac{\partial\xi}{\partial y}\lambda(\xi),\\ w&=\phantom{f(\xi)+{}}x\frac{\partial\xi}{\partial z}\lambda(\xi),\end{aligned}\right\} \tag{13.15}$$

where ξ, η, ζ are the ellipsoidal co-ordinates.

He finds the drag co-efficient and the existence of the boundary layer in the vicinity of the solid.

For a sphere he shows that the drag co-efficient is of the order $R^{-0\cdot60}$ and the relative thickness of the boundary layer is of the order $R^{-0\cdot4}$. The order of this thickness is always found to be greater than the standard value $R^{-1/2}$.

This method has been extended to a parabolic cylinder by Y. D. Wadhwa(120). He takes u and v as

$$\left.\begin{aligned} u&=f(\eta)+\frac{\partial\eta}{\partial x}\phi(\eta),\\ v&=\phantom{f(\eta)+{}}\frac{\partial\eta}{\partial y}\phi(\eta),\end{aligned}\right\} \tag{13.16}$$

and finds that the thickness of the boundary layer is not of order $R^{-1/2}$ as found by Dean, but is of order $R^{-k/(2+\lambda)}$ where $0<k<1, 0<\lambda$, so that $k/(2+\lambda)$ is less than $1/2$, R being the Reynold's number.

Ludford(124) has indicated an analogy between the boundary layer equations and those for shocks. J. R. Foote(121) has used this method for the motion of a sphere through a compressible fluid. It is therefore possible that the synthetic approach may give a satisfactory method for the treatment of shock waves.

14. NON-NEWTONIAN FLUIDS

In non-Newtonian fluids the stress-strain velocity relations given in (3.13) are modified by the introduction of second degree terms. The relations given by Reiner(59) are

$$p^i_j = F_0\delta^i_j + F_1 d^i_j + F_2 d^i_\alpha d^\alpha_j. \tag{14.1}$$

$$d^i_j = \frac{1}{2}\left(\frac{\partial u^i}{\partial x_j} + \frac{\partial u^j}{\partial x^i}\right). \tag{14.2}$$

Reiner(63) and Rivlin (28) use these relations to obtain a variety of Poynting and Kelvin effects. Kelvin effect is also known as dilatancy. For shear flow between two parallel infinite plates it is found that shearing forces alone are insufficient: in addition stress normal to the plate must be applied, which is an example of Poynting effect. Poiseuille's flow gives another such example.

For Couette flow in which liquid is contained between rotating cylinders it is found that normal pressure must be applied to the planes perpendicular to the axis. If these pressures be wanting, the fluid surface will tend to rise, whatever be the speeds and senses of rotation. This Poynting effect is also called the cross-viscosity effect. Similar results have been obtained for a parallel plate viscometer.

S. D. Nigam(126) shows that the 'cross-viscous' effect is opposite in nature to the 'inertia effect'. When an infinite plane lamina is rotated impulsively from rest with a uniform angular velocity about an axis perpendicular to the plane of the lamina in non-Newtonian liquid he finds that the liquid flows axially away from the lamina and flows radially inwards (cross-viscous effect) near it in the early stages of motion. In the case of a Newtonian liquid, there is an axial flow towards the lamina and the fluid moves radially outwards near it (inertia effect).

15. SYNTHETIC METHOD FOR NON-NEWTONIAN FLUIDS

In a recent paper M. K. Jain(122) applies the synthetic method to the motion of a sphere or a circular cylinder in a non-Newtonian liquid. Using (13.1) his solution shows that, a boundary layer is found in the immediate vicinity of the body, the motion remaining irrotational elsewhere. The effect of cross-viscosity like that of viscosity is also confined to this layer. The drag co-efficient remains un-effected by cross-viscosity.

In the treatment of Couette flow between two rotating cylinders he finds a striking analogy between the effects of cross-viscosity and the effect of a magnetic field on a liquid heated from below. This analogy helps him to make use of the methods adopted by Chandrasekhar(123) and others for numerical calculations.

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(1920-24) developed in some detail the theory of the rotating anharmonic oscillator and applied it to the analysis of infra-red as well as of simple optical bands. He also made considerable progress towards the understanding of the visible and ultra-violet bands of more complicated structure extending the work of Heurlinger. Kemble (1920) and his collaborators made valuable contributions to our knowledge of infra-red bands. At the same time and later (1920-25) a number of workers notable among whom are Hulthen, Mecke, Birge, Curtis, made important contributions to our experimental knowledge and theoretical understanding of the structure of complicated bands. In this development of the Bohr form of quantum theory of band spectra of di-atomic molecules, the usual classification states that there are widely spaced electronic levels on which are superposed medium spaced vibrational levels on each of which again are superposed the rotational levels with small spacing. If the molecule is regarded as a rigid rotator its spectrum would lie in the far infra-red and from the constant interval between successive rotational lines the moment of inertia and hence the internuclear distance can be evaluated. The molecule as a harmonic oscillator would give a specturm lying in the near infra-red at a frequency which is its fundamental vibration frequency from which the force constant can be evaluated. Such a spectrum will possess a rotational structure from which again as in the far infra-red band, the moment of inertia and the internuclear distance may be calculated. Apart from certain fundamental difficulties which were removed by quantum mechanics, as will be shown presently, this interpretation of the two infra-red spectra has been confirmed by a large amount of experimental data. The theory also includes the treatment of the molecule as non-rigid rotator and anharmonic oscillator.

(2) *Quantum Mechanical Theory*

Inspite of this, quantum theory as applied to these developments in the systematics of molecular spectra was never so satisfying as it seemed to be in the case of the hydrogen atom There were difficulties from the very start. First, in order to explain in terms of the quantum theory, the rotational structure which was well resolved in the work of Imes (1919), of the HCl vibration-rotation fundamental band at 3.46μ, it was necessary to use half-integral values for the rotational quantum number for which there was no justification in theory. This was analogous to a similar difficulty in atomic spectra regarding the Lande splitting factor (1921) which determines the Zeeman pattern in multiplets. Secondly, Pauli[2] (1922) calculated the ionisation potential for H_2 on the quantum theory. The value came to be 23.7 e.v. whereas the experiments of Richardson and Tanaka[3] (1924) gave 15.9 e.v. (present value 15.422 e.v.). Thirdly, Mulliken's (1923) work on the isotope effect in the band spectra of BO, proved the necessity of using half integral numbers for the vibration quantum. Finally, Czerny's work (1925) on the pure rotation bands of the hydrogen halides showed conclusively that the expression of the quantum theory for the rotational energy of a diatomic molecule cannot be correct. Thus, on this theory the wavenumbers of the absorption lines are given by $\sigma = 2BJ + B$; where, $B = \frac{h}{8\pi^2 I}$ and $J = 0, 1, 2$ .... According to this, the first line would lie at $\sigma = B$ and the successive line separation would be $2B$. Actually, in the case of the rotation bands of HCl and HBr a fairly large number of lines were observed and represented to a high degree of accuracy by empirical formulae which showed that the first line lies not at $\sigma = B$ but rather at $\sigma = 2B$ which is also the successive line separation. These difficulties were removed effortlessly by the quantum mechanical treatment which gives the energy of the rotator as $E_{(J)} = \frac{h^2}{8\pi^2 I} \cdot J(J+1)$, where $J = 0, 1, 2$. . in place of the older $E_{(J)} = \frac{h^2}{8\pi^2 I} \cdot J^2$ and the wavenumbers of the absorption lines as $\sigma = 2B(J+1)$. This gives $2B$ for the position of the first line ($J = 0$) as well as for successive line separation as demanded by experiment. Similarly the energy of the oscillator is given by $E(v) = h\nu_{osc.}(v + \frac{1}{2})$, where $v = 0, 1, 2, ..$ in place of the older $E(v) = h\nu_{osc.} \cdot v$ thus confirming Mulliken's half integers for vibration quanta and showing that the molecule even at the zero vibrational level possesses an energy $E_{(0)} = \frac{1}{2}h\nu_{osc.}$, now well-known as the zero point energy.

B. ELECTRONIC SPECTRA

The next development started near about 1925 through investigations not on the simpler infra-red absorption bands but on the more complicated electronic emission bands of di-atomic molecules and radicals in the visible and ultra-violet regions. This was due to several reasons. The experimental techniques in the infra-red region till very recently have not been easy. The investigations are mostly limited to absorption spectra* of chemically stable molecules. The common diatomic gaseous molecules such as H_2, O_2, N_2 having no permanent electric dipole moment, do not have, ordinarily the usual dipole spectra in the infra-red**. On the other hand, the methods of production and measurement of the electronic spectra which usually lie in the visible and ultra-violet regions are comparatively simple at least for several emitters, and were sufficiently well advanced. Above all, the success of the new quantum mechanical theory of the rigid rotator and the harmonic oscillator gave the necessary confidence to proceed ahead with the work, already begun, of systematizing the fairly large amount of the empirical data which was on hand and extending their interpretation in terms of the quantum theory of molecular spectra. According to this theory such spectra are to be attributed to electronic transitions in the molecule like in the atom. Here, however, not a line or lines as in the atom, but a system of bands results, due to a transition between two electronic states: a set of characteristic vibrational levels accompanies each electronic level on account of the molecule being an anharmonic rotating oscillator: every one of the vibrational levels again is attended with a large number of rotational levels due to the molecule being a non-rigid rotator. Transitions between various vibrational levels of one electronic state and of another thus give rise to a large number of bands each with a complicated structure due to transitions among the rotational levels.

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* So far only in one instance that of HCl, the pure rotation spectrum has been observed in emission in a chlorine-hydrogen flame by Strong[1] (1934). Again the Meinel bands[5] (1950) found in the spectrum of the light of the night sky and identified as the vibration rotation emission bands of OH provide the only instance so far known of emission vibration bands of a radical.

**They show such rotation and vibration spectra in Raman effect (1928) and were investigated only later (Rasetti[6] 1929, Teal and MacWood[7] 1935). They should show vibration spectra in quadrupole radiation which, however, will be very weak in intensity (10^{-9} of dipole radiation). Such a spectrum of H_2 has been observed recently (Herzberg[8] 1949). They may also show vibration spectra in enforced dipole radiation under certain conditions. Crawford, Welsh and Locke[9] (1949) have observed the fundamental vibration bands of these molecules in absorption at high pressures.

(1) *Gross-structure Analysis*

The first step in the practical analysis of such band spectra consists in grouping the bands into systems and in analysing and organizing each system by a determination of the correct vibrational quantum number for each band of the system. Generally this vibrational analysis can be done even though the rotational structure is not resolved enough for analysis, by using the data on the heads of the bands but very often rotational structure or other information like isotope effect is necessary. Such a gross structure analysis of the entire spectrum of a molecule gives information about the electronic levels, the vibrational frequencies, the anharmonicities and the force constants of the molecule in its various electronic energy levels. Rapid progress was achieved notably by Mecke, Birge and Mulliken among others and several significant contributions are due to them. They found that the displacement law (Kossel-Sommerfeld) and the law of multiplicities in line spectra hold good also in band spectra. They also pointed out certain analogies existing between the electronic levels of iso-electronic molecules among themselves and those of corresponding atoms although this latter analogy with the atoms was found later to be remote. Notable steps in the history of the analysis and theory of vibrational levels taken in the early period are the Franck-Condon principle for the explanation of the types of intensity distribution found in band systems, the Morse potential energy function, the application of isotope effect for band analysis and the determination of dissociation energies from converging progressions in absorption bands under favourable conditions or by extrapolation of observed vibrational levels to the convergence limit first pointed out by Birge and Sponer (1926).

The work of the early investigators in the field of vibrational organization was difficult and slow and uncertainty existed regarding the emitters of the band systems although bands could be organized and analysed. Particularly embarrassing was the difficulty of ascertaining the emitters for the most easily obtained and ubiquitous bands in a discharge tube containing nitrogen, air or carbon or small traces of them. The usual classification of bands was in terms of positive and negative systems supposed to be due to the neutral and ionized molecule respectively, depending on whether the bands were more strongly developed in the positive column of the discharge tube or near the cathode. There was also in a few cases the classification in terms of the low and high pressure bands depending on sensitiveness of the bands to pressure. An illustrative example is the case of the so-called carbon bands. Five positive systems, two negative systems (also called Deslandres bands and low pressure carbon or comet tail bands) one high pressure carbon band system were all known as the carbon bands. Vibrational analysis (Birge 1925) had shown that the two negative systems had a common final electronic level and therefore belonged to the same molecule, probably CO^+. Similarly Birge (1926) showed that the final electronic level of the second positive system also known as the Angstrom bands, was the same as the initial electronic level of the fourth positive system which was further shown to include the bands originally classified as the fifth positive bands. The first and third positive bands and the high pressure bands showed no relationship to any of these bands. Cameron[10] (1926) then discovered a set of bands in the ultra-violet in the spectrum of a discharge through neon containing a trace of carbon. These were analysed and correctly interpreted by Johnson[11] (1926) who discovered that the initial level of the Cameron bands is the same as the final of the third positive bands and that the final level is identical with the final electronic level of the fourth positive bands. Leifson (1926) obtained the fourth positive bands and Hopfield (1927) also the Cameron bands, in absorption in CO. The investigations on CO thus assumed an importance for the development of the theory. In the course of a few years several more systems were discovered by various workers. The CO molecule is now one of the few molecules next to H_2, He_2 and N_2 for which a comparatively large number of electronic levels are known. The high pressure bands were shown to be related to the first positive or Swan bands by having a common final state and therefore due to C_2 (Johnson and Asundi[12] 1929). According to Herzberg[13] (1946) they form part of the Swan system and the formation of the C_2 molecule responsible for the emission of only the high pressure bands exclusive of the rest of the bands of the system is tentatively attributed to the mechanism of inverse predissociation leading to a recombination of the dissociation products in a two-body collision.

The theory of the electronic structure of diatomic molecules has been a good guide in the search for new band-systems and in obtaining the correct analysis of many of the already known ones. For instance, considerations of electronic structure indicated $^2\Pi$ as the ground level of SiF instead of $^2\Sigma$ as previously assumed. It was indeed possible, on this basis, to give a satisfactory analysis of all the SiF bands, which had not been possible before (Asundi and Samuel[14] 1936). Such vibrational analysis has now been carried out, through the work of many investigators, for one or several band systems of each of a considerable number of molecules. The number of molecules analyzed is, however, very small compared to the mathematically possible combinations of atoms in pairs and the still larger number of electronic transitions (band systems) which are possible for each such pair of atoms. Furthermore, only a small number of vibrational levels of low quantum numbers are now known for most of the electronic states. There is also considerable room for improvement in the accuracy of the molecular constants already obtained. Finally, it would be extremely useful if we get to know the higher vibrational levels of each electronic level as well as a larger number of electronic levels for each molecule. We would then have not only a wider but also a more accurate knowledge of the forms of potential energy curves and a more complete and satisfactory knowledge of the dissociation products and dissociation energies of the molecules.

(2) *Fine Structure Analysis*

The form of the potential energy function of the molecule as an anharmonic oscillator, depends among other factors, also on the mutual interaction of vibrational and electronic motions. Now the potential energy curve for any electronic state can be constructed point for point and this interaction thus essentially taken into account from the observed vibrational and rotational levels without assuming any analytical expression (the Morse function for example) for the potential function. Also the vibrational constants (viz : frequencies, anharmonicities and force constants) and the positions of the electronic levels will be known very accurately if the origins (zero lines) of the bands are used and not the band heads. For these reasons rotational analysis of the band structures is very important. Furthermore, the greater part of our informtion about electronic levels is obtained together with that on nuclear rotations, moments of inertia and several other properties of the nucleus only from a detailed fine structure analysis of the bands. This is because of the mutual coupling between nuclear rotations and electronic orbital rotations and spins such that the structure of the bands although due primarily to nuclear rotations is greatly dependent on the nature of the electronic states involved.

(*a*) *Quantum Theory*

Many types of band structures for each molecule thus result from transitions between different kinds of electronic states. They have to be classified not according to molecules as in the vibrational organization but according to the typical transitions. The task, therefore, of organizing and correlating these types empirically, has been more difficult than that of vibrational classification. The first steps in the systematic investigation of band structures depending upon the nature of the electronic states involved, were taken by Kramers and Pauli, Kratzer, Hulthen, Mecke and others. But the clue to the clarification of the many moot and intricate problems that arose in this type of work came essentially through the work of Hund (1926-29) and of Mulliken (1926-29). Hund investigated the meaning of the circumstance that if the distance between the nuclei is made infinite two separate atoms will result while if it is made to approach zero, the molecule will be transformed into a single atom. In the first possibility, the energy values of the electronic levels of the molecule will go over into the sum of the energy values of the resulting atomic levels; in the second case they will go over after deducting the mutual potential energy of the nuclei, into the energy values of an atom whose nuclear charge is the sum of the charges of the two original nuclei. The first of these at least, can be realised in practice and so it should be possible to co-ordinate molecular electronic energy levels to atomic levels. Hund was thus able with the help of the vector model to extend to the diatomic molecule his interpretation of the electronic energy levels of the atom in terms of the orbital and spin angular momenta of the electrons. This enabled the classification of electronic states of molecules in terms of suitable characteristic quantum numbers. These are Λ, the component of the electronic orbital angular momentum (L), Σ, the component of the electronic spin angular momentum (S), and Ω, the resultant angular momentum $\Lambda+\Sigma$, all along the internuclear axis. On account of the interaction of spin (S) with the magnetic field due to Λ, there will be $2S+1$ different values of $\Lambda+\Sigma$ with somewhat different energies of the resulting molecular states, so that an electronic term with $\Lambda \neq 0$, splits into a multiplet of $2S+1$ components. $2S+1$ is called the multiplicity of the state exactly as in atoms, including the case for $\Lambda=0$. Thus the notation for a molecular electronic state is $^{2s+1}\Lambda_{\Omega}$ compared to that of the atom $^{2s+1}L_J$.

A further decisive step was taken when Hund (1926-29) investigated the interaction between nuclear rotation and electronic motion and spin. He worked out the main types of coupling cases, now known as Hund's coupling cases, which could be expected theoretically on the vector model and discussed the question of fine structure. In a brief review of the empirical data he presented evidence of good agreement with his theory. Mulliken (1926-29) had achieved considerable success in his empirical studies of correlating band structures with electronic states independently of the lead taken by Hund. He now reviewed the data in terms of Hund's theory and discussed the coupling cases and amplified them in terms of the existing experimental evidence on the fine structure of the bands which he could marshal so skilfully. He showed that practically all the available evidence was in agreement with the theory. Selection rules and intensity relations which had been treated only briefly by Hund were discussed in greater detail in terms of the Correspondence Principle Theoretical intensity formulae were obtained with the help of summation rules for Hund's case (b) and found to be satisfactory. This was practically the limit to which the Bohr form of quantum theory could be extended by the help of empirical data. There were, however, several outstanding difficulties. Foremost among these were the question of alternating intensities observed by Deslandres (1903) and alternating missing lines guessed by Heurlinger (1918) in the spectra of molecules with identical nuclei, and the anomalous selection rules found for σ-type (now called Λ-type) rotational doubling.

(*b*) *Quantum mechanical Theory*

(i) Λ-doubling; (ii) Intensity alternation : Nuclear spin.

Slater, Born and Oppenheimer, Kronig, Hill and Van Vleck with wave mechanical methods and Wigner and Witmar with the methods of group theory were able to develop a good general theoretical frame work (1927-29). These quantum mechanical considerations not only justified all the results obtained by Hund and substantiated by Mulliken on the vector model but led to several new consequences. Selection rules and intensity factors for different coupling cases have been derived for electric and magnetic dipole and electric quadrupole radiations. These results have been confirmed from time to time by examples of representative band structure which have been investigated. Quantum mechanical treatment further shows that the symmetry properties of the electronic eigen-functions are also of great importance for the classification of electronic as well as rotational terms. These symmetry properties depend on the symmetry properties of the field in which the electrons move. For all diatomic molecules this field has a symmetry axis (the internuclear axis) and in addition has a centre of symmetry if the two nuclei possess the same charge. Thus all molecular electronic and rotational states are classified into positive and negative terms and those of molecules with identical nuclei further into gerade and ungerade terms. For gerade terms, positive rotational terms are symmetric and the negative anti-symmetric in the nuclei and vice versa for the ungerade terms. It is these quantum mechanical properties of the rotational levels that explain the so-called anomaly of the σ-type rotational doubling and the mystery of the alternating intensities in the spectra of homonuclear molecules. Thus it is shown that in the case of degenerate rotational levels (i.e. $\Lambda \neq 0$) the positive and negative states which have exactly equal energies split, under the influence of rotation into two components of slightly different energy. These are usually distinguished in empirical analysis by subscripts c and d, c-levels being those in which the even rotational levels are positive and the odd negative and vice versa for the d-levels The selection rule that positive terms combine only with negative ones and vice versa removed the empirical anomaly in the observed transitions. Similarly as shown by Heisenberg[15] (1927) and Hund[16] (1928) the intensity alternation is caused by nuclear spin, the ratio of intensity (weak : strong) being given by $I/(I+1)$ where I is spin of nucleus. alternate lines will be entirely missing if $I=0$. The type of alternation, whether the anti sym. levels or the sym. ones are weak or entirely missing, is determined by another important property of the nucleus, the statistics of the nucleus, which may be either Bose-Einstein or Fermi-Dirac. Thus both the spin values and the nuclear statistics are easily determined by this striking phenomenon which was seen but not understood for a quarter of the present century.

This phenomenon provided the most conclusive evidence for the present view that the atomic nucleus consists of protons and neutrons and not of protons and electrons. The spin of the nitrogen nucleus was known to be $1\times h/2\pi$ by the measurements of Ornstein and Van Wyck[17] (1928) on the intensity ratio of the lines in the emission electronic spectrum of N_2^+. Soon after the discovery of Raman effect, Rasetti[6] (1930) obtained the rotational Raman spectrum of nitrogen. The analysis proved beyond doubt that it was the odd-numbered (anti sym.) rotational levels that are the weaker and that therefore the nitrogen nuclei follow Bose-Einstein statistics. They thus contain an even number of particles which was not possible on the older view.

The spin of nucleus also causes hyperfine structure in the spectra of all molecules as it does in atoms. The magnitude of the splitting, however, depends on the nuclear magnetic moment and even more so on the nuclear electric quadrupole moment. Such hyperfine structures in molecular spectra have been studied more recently in a few cases of diatomic molecules by the use of microwaves or molecular beam magnetic resonance method. But the value $I=0$ is very difficult to ascertain from hyperfine structure. The apparent absence of splitting may be due to very small magnetic or quadrupole moment. On the other hand if the band of the corresponding homonuclear molecule shows alternating missing lines the value $I=0$ is immediately established without ambiguity. For very high values of I, however, the intensity alternation is very slight and it is difficult to obtain a unique value of I. The nuclear statistics cannot be determined by hyperfine structure. Apart from investigations on collisions between identical nuclei, intensity alternation phenomenon is the only means for determining the nuclear statistics.

(iii) Perturbation and Predissociation : Quantum Mechanical Resonance and Tunnel effects

The phenomena of perturbation and predissociation with their rich variety of types in molecular spectra provide very good illustrations of the quantum mechanical resonance and tunnel effects. Perturbations in the fine structure lines of di-atomic electronic bands have been observed since the days of Deslandres (1885). These consist in one or several successive lines being displaced more or less strongly from their normal positions. Sometimes splitting of one or more successive lines into two each takes place. In some cases the intensity of one or more lines in the band becomes abnormally small. In another type the displacement and weakening in intensity appear together. When perturbation affects successive lines the displacement increases rapidly from line to line upto a maximum and then suddenly decreases to zero, like in a resonance effect. Sometimes displacement of band head from its position is observed. This is known as vibrational perturbation but essentially it is due to the rotational perturbation affecting either just some lines of the band near its head in the usual way, or affecting all lines of the band to an equal extent. Perturbations are produced by the mutual interaction of two states of nearly the same energy, of the same J value and of the same parity (+, –) and symmetry with respect to an exchange of identical nuclei. The systematic explanation of the different types of perturbations in terms of the above selection rules derived from quantum mechanical consideration by Kronig (1928) and from an application of the Franck-Condon principle, on which depends the mutual interaction that governs the magnitude of the effect has resulted in a closer study of the phenomenon and led, in many cases, to definite conclusions with regard to the quantum characterization of the perturbing state which very often cannot be directly observed.

The phenomenon of predissociation was first observed and named as such by Henri[18'] (1923) who found that in the absorption spectrum of S_2, bands involving low vibrational levels in the excited electronic state have sharp rotational lines as usual but that in bands involving higher vibrational levels the rotational structure has become diffuse. A related phenomenon occurring in emission, is the sudden breaking off of band structure at certain rotational levels or in some cases a sudden drop in the intensity of the band structure. This abrupt termination observed in emission is also usually due to predissociation of the molecule (in highly excited states it may be due to preionization). Indeed for S_2 only those bands appear in emission which correspond to the sharp absorption bands whereas the bands of the same system which are diffuse in absorption are entirely absent so that in emission the band system breaks off at a definite value of the vibrational quantum number in the excited state. All these types of predissociation are understood in terms of the resonance effect as in perturbation but here the perturbing cause is not a discrete stable level but a repulsive state of the molecule or a continuous term spectrum following a dissociation or ionization limit (when the phenomenon is termed pre-ionization) of the molecule. Predissociation is more common in poly-atomic molecules because its possibility is much greater there due to the larger number of possible dissociation limits of different vibrations. Essentially, it is due to the process of spontaneous decomposition of the molecule by a radiationless transition from a discrete into a continuous state of the molecule, analogous to similar phenomena observed in the spectra of several atoms (pre-ionization) and to Auger effect in X-rays. It is a special case of perturbation and exactly the same selection rules and the Franck-Condon principle hold good. The probability of the radiationless transition depends on the mutual interaction of the two states which can be calculated on the basis of their eigenfunctions. This determines the broadening and therefore the diffuseness of the absorption bands involving the affected discrete levels.

Predissociation by *rotation* is also an observed phenomenon in which, however, the decomposition results without any transition from one electronic state to another. Rather, it is brought about by the passage of the molecule through the potential hill to the dissociated state under the influence of the quantum mechanical tunnel effect. This has been investigated in detail by Farkas and Levy[19)] in the case of AlH and AlD. A similar case (but in ordinary predissociation) of tunnel effect allowing a passage through the potential hill formed by two intersecting potential curves is observed by Herzberg and Mundie[20)] in S_2. The study of the phenomenon of predissociation has led to several valuable conclusions concerning molecular structure. It has also been of value to an explanation of some photo-chemical processes and to the determination of heats of dissociation of molecules.

(iv). Isotope Effect.

Isotope effect has been of great value in molecular spectra. In the case of diatomic molecules it helps in the vibrational analysis of the electronic bands and in the determination of the molecule giving rise to the observed band system. It gave conclusive evidence for the existence of zero point energy and an unambiguous confirmation of the quantum mechanical formula for the energy of the oscillator.

A study of the effect led first to the discovery of oxygen isotope of mass 18 and later to that of 17 and also to several other rare isotopes e.g. C^{13}, N^{15} and In^{113}. The discovery of O^{18} was significant because it led to a scrutiny of the apparent agreement between the mass spectrographic and the chemical atomic weight of hydrogen. This resulted in the discovery of the heavy isotope of hydrogen (D). An elaborate theory of the isotope effect in band spectra is developed by Kronig (1934) Dieke (1935) and Van Vleck (1936) which accounts in a general way for the slight discrepancies between the elementary theory and the observed values for isotopic shifts particularly in the spectra of deuterides and corresponding hydrides. Also a nuclear isotope effect due to deviations from a coulomb field near isotopic nuclei has been observed by Mrozowski[21] HgH, HgH^+ and ZnH.

To arrive at a satisfactory and complete analysis of the rotational structure of an empirically observed band system is more often difficult than easy. On the experimental side, spectrographs of high light gathering power, having not only sufficient resolution but also dispersion are absolutely necessary. Even for the simplest of band structures (e.g. $^1\Sigma-^1\Sigma$ transition in a comparatively light molecule like BeO) where only two branches are encountered in each band, the service of the first order of a 10-foot concave grating with 6000 lines/cm. is required. A band due to transition $^3\Pi$ $^3\Sigma$, case (a) will consist of 27 branches and will need the third or fourth order of a 21-ft grating even if the molecule is a comparatively light one, e.g. CO. The phenomena of perturbation and predissociation, however significant they may be for other problems, are often unwelcome since they increase the difficulty of analysis by destroying regularities in the structure of band spectra or by wiping it out completely. Apart from the experimental difficulties that arise under such circumstances, the types of the upper and lower electronic states have to be established by the analysis of several suitable bands of the system and by working out as many criteria and mutual checks as are possible. It is clear that a reliable determination of the molecular constants is only possible when such complete analysis is achieved. These are just the data that are of great importance for many applications as well as for progress in the theoretical understanding of molecular structure. Among those who have been particularly active since 1925 in the measurement and analysis of diatomic bands and particularly their structure have been Mulliken, Hulthen, Richardson, Dieke, Watson, Weizel, Jenkins, Jevons, Johnson and Herzberg. Several other excellent workers have also been making important and extensive contributions.

C. RECENT DEVELOPMENTS

(1) Improved Methods

In more recent years increasingly accurate determinations of molecular constants of di-atomic molecules are being made by microwave absorption spectra (for rotational constants) and by more powerful spectrographs. Considerable progress has been achieved on the side of instrumentation and good gratings of large aperture and blazed to throw the intensity in any desired spectral region are becoming increasingly available. Progress in vacuum techniques has resulted in the possibility of setting up of large vacuum grating spectrographs of high resolution and dispersion suitable for work in the vacuum ultra-violet region. These combined with the echelle developed by Harrison[22) are inviting more results in this relatively less explored field. The multiple reflection mirror arrangement of increasing the effective length of absorption path without actual increase in the tube length first proposed by White[23) has been put to much profitable use particularly by Herzberg and collaborators[24) in the investigations of forbidden transitions and in the study of the absorption spectra of free radicals produced by flash photolysis.

(2) Microwave and Radio-frequency Methods.

Microwave and radiofrequency spectroscopy including molecular beam magnetic and electric resonance spectra have heralded a new era in experimental spectroscopy. Our knowledge of diatomic molecules has come mainly through electronic spectra where vibrations and rotations are studied together with interaction effects and partly through vibration spectra where rotation is studied including interaction. Pure rotation spectra had received very little attention for reasons mainly of experimental difficulties. The microwave region, however, covers rotational frequencies of all but the lightest molecules. Moreover, in vibrational and electronic spectra, the rotational frequency is obtained as a small difference between two large numbers. Its relative accuracy may, therefore, be quite low. In the microwave region, however, it is measured directly and so can be obtained with a much higher accuracy. (An accuracy, for instance, of one part in two million in the measurement of a wavelength at 5000 A gives an accuracy of 0.01 in wave numbers. Hence a rotational frequency of one wave number measured as the difference between two such wavelengths can be obtained only to an accuracy of 1 per cent, whereas if the same frequency is measured directly in the one centimetre region it can be obtained without much difficulty with the full accuracy of one part in two million). Also with increasing wavelength the resolving power in wave number units increases rapidly for a given resolving power in wavelengths. This coupled with the fact that the natural line width in wave number units is also very much smaller than in the visible region, (e.g. the natural half width is, at $2000\text{A} = 3 \times 10^{-3}\sigma$, at $5000\text{A} = 4.8 \times 10^{-4}\sigma$, while at $1\ \text{mm} = 1.2 \times 10^{-10}\sigma$), explains the possibility of making much more accurate measurements than is possible in the optical region. Because of the rapid decrease in the coefficient of spontaneous emission with frequency microwave emission spectra are, however, extremely difficult to detect under ordinary laboratory conditions. Absorption spectra are by far the easier to detect at microwave frequencies. This method has been employed to obtain the rotational constants of a large number of different types of poly-atomic molecules and also of several diatomic ones like CO, ICl etc. The rotational spectra thus observed exhibit in several cases a hyperfine structure produced not so much by the nuclear magnetic dipole moment due to spin as in the atomic case, but more prominently by nuclear electrical quadrupole moment due to the electric charge of the nucleus being, in general not distributed in a spherically symmetrical way. The rotational constants, nuclear spin and electric quadrupole moment and isotopic mass-ratios may be obtained by this method. A severe restriction ruling out many interesting molecules is that its use is essentially confined to molecules having a permanent dipole moment. The case of O_2 is of particular interest because the spectrum observed is due to magnetic dipole absorption and represents a transition not between different rotational levels but a transition between the fine structure components of given rotational levels. It might be described as a spin-multiplet or spin-reorientation spectrum. Another interesting spectrum obtained is that of the free radical OH and represents a direct transition between Λ-doublets of the $^2\Pi_{\frac{3}{2}}$ ground state of the molecule. Such data are very interesting for quantum mechanics and one could think of several such examples for working out particularly by the para-magnetic resonance method.

Similarly in micro-wave and radio-frequency magnetic resonance spectra applied to molecular beams, transitions between the hyperfine structure components in a magnetic field give the nuclear magnetic moments. The electric analogue of the magnetic resonance method causes transitions in an oscillating electric field between the Stark components of a rotational level. Electric dipole moments, moments of inertia and quadrupole interactions can be determined with high accuracy by this method. Similar methods are also employed with atomic beams. Other methods such as nuclear magnetic resonance, nuclear induction and nuclear quadrupole resonance have been applied to matter of ordinary density such as liquids and solids as well as gases for the study of nuclear properties.

The amount of data accumulated so far in di-atomic molecular spectroscopy is no doubt considerable and concerns a large number of molecules whose fine structure analysis has been done but in several cases one would like to have more illustrative examples than just the one or two which are now available for several types of transitions. Much work remains, however. to be done both with regard to molecules that have not yet been investigated and with regard to new electronic states of known molecules. A whole lot of spectra involving multiplicities greater than three awaits attention. Only two $\Pi-\Sigma$ transitions of multiplicity higher than three have so far been analysed in some detail. In O_2^+ bands of quartet transition 40 of the 48 possible branches and in MnH bands of septet transition 49 of the 147 possible branches have been identified (Nevin)[25]. Diffuse and continuous spectra of diatomic molecules are known but not studied in detail. Rydberg series of bands or band systems for many diatomic molecules have to be studied. So far such series are known only in the case of a very few molecules e.g. H_2, He_2, O_2, N_2, CO, NO and HI. The convergence limit of the series or the long wave limit of the continuum which follows gives an exact value for one of the many ionization potentials of the molecule. Since most of the ionization potentials are greater than 10 e.v. the Rydberg series and ionization continua lie in the far vacuum ultra-violet. Recent advances in the techniques of vacuum spectroscopy are expected to lead to a better knowledge in this direction.

A great deal of work remains to be done in the accurate measurement of intensities of band-lines, bands and band-systems as a whole. There are also quite a number of small but interesting points concerning even the spectra of such simple molecules like N_2 and C_2 which remain to be clarified. Particularly important will be a thorough investigation of the spectra of the six species of hydrogen molecules H_2, D_2, T_2, HD, HT and DT. Hydrogen is the simplest of the diatomic molecules which allows one to obtain a complete theoretical treatment of all its details which cannot be quantitatively treated in the heavier molecules. Such an investigation is already in progress (Dieke and Tomkins[26] 1949). Another example is that of the three species of helium molecules He_2^4, He_2^3, He^3, He^1, of which He_2^4 and He_2^3 are also fully worked out (Douglas and Herzberg[27] 1949, Dieke and Robinson[28] 1950). There is also considerable room for excellent work in regard to the spectra of normally forbidden transitions and the structure of bands that arise from them. On the whole, however, theory and experiment have here established a systematic structure which makes it possible to comprehend the remarkably large variety of the spectra under a uniform view-point. "*yasmin vijñāte sarwam idam vijñātam bhavati**", aptly describes the mutual stimulation that exists between the quantum mechanical theory and the enormous experimental wealth of details of diatomic molecular spectra.

IV. SPECTRA OF GASEOUS POLYATOMIC MOLECULES

A. INTRODUCTION

The development of polyatomic molecular spectroscopy has taken a somewhat different course. Here again one distinguishes the three types

यस्मिन्विज्ञाते सर्वमिदं विज्ञातं भवति ।

of spectra — the rotation, the vibration and the electronic. The study of these spectra is expected to yield, as in the diatomic case, precise information about their rotational, vibrational and electronic energy levels and thus lead to the evaluation of the molecular constants that determine their size, shape and structure e.g. internuclear distances, vibration frequencies, force constants etc. But there are several internuclear distances, several vibration frequencies, force constants and so on which destroy the relative simplicity of structures met with in the spectra of diatomic molecules and make them very complicated for an empirical study. Again, all of the three types of spectra have to be investigated, more or less, by way of absorption only. It is difficult to produce in emission even their electronic spectra which in the case of diatomic molecules are the more easily obtained in emission and in greater number. The data on rotation and vibration bands whose structures will be relatively less complicated and which lie in the difficult spectral regions have been till recently, very few. On account of all these reasons, an empirical approach has not been successful or found practicable. On the other hand, the enormous wealth of details available in diatomic molecular spectra have established the quantum mechanical method as the appropriate one for the explanation of spectra. This method upheld almost entirely the systematization of spectra achieved semi-empirically on the basis of quantum theory. It went beyond it and led to a deeper understanding not only of the phenomena which were un-understood but of all the finer details connected with them. Although the quantitative application of quantum mechanics to the detailed understanding of the structure of molecules is found to offer enormous mathematical difficulties, its methods have always proved satisfactory to understand the structures of spectra and related phenomena for which detailed computations are less essential. Therefore, the general procedure has been to develop the theory of the spectra and then use it as a guide to interpret the observed spectra.

Historically, interest in polyatomic molecular spectra was revived by the discovery of Raman effect in 1928. Raman spectra may be regarded, in a way, as infra-red spectra shifted into the conveniently accessible optical region. The occurrence of Raman spectra depends on whether the polarizability of the molecule in fixed direction changes during the motion. They, therefore, allow one to study the rotation and the vibration spectra also of molecules which do not possess permanent dipole moment. They yield data complementary to those obtained by the usual methods. On account of the inherently small intensity of such spectra instruments of large light gathering power with corresponding loss of dispersion have been mostly employed till recently. The investigations, apart from the very important cases of diatomic molecules, concerned themselves mostly with vibrational spectra of polyatomic molecules in the liquid or solid states. Raman spectra of solids and liquids do not in general show a rotational fine structure but consist of lines which correspond more or less to the null lines of the vibration bands in infra-red spectra. Therefore, they have been of particular importance together with infra-red data in correlating the frequencies to modes of normal vibrations.

Another stimulus for polyatomic molecular spectroscopy came through the development of radar out of which has grown the new field of microwave spectroscopy where one encounters the pure rotation spectra of most of the polyatomic polar molecules. The enormous resolving power coupled with dispersion which is easily obtainable in this method has not only put quantum mechanics to hard service and occasional severe test but has revealed several new features which are of fundamental importance not only to the theory of spectra but also to nuclear physics. This branch of spectroscopy is growing very rapidly and is using already a large variation of techniques such as microwave and radiofrequency molecular beam magnetic and electric resonance methods, the nuclear induction method, the nuclear magnetic resonance method, the nuclear quadrupole resonance method and so on. This development is remarkable for the simplicity and the variety of results obtained for the molecular constants and the nuclear properties. As a result of all these discoveries and developments our knowledge of the rotation and vibration spectra of polyatomic molecules is more advanced than that of their electronic spectra which are still, comparatively, in the exploratory stage.

B. VIBRATION SPECTRA

A knowledge of the shape of the molecule (i.e. whether it is linear or bent and so on) gives an important clue to the study of its spectrum. Molecules having different types of symmetry (symmetry of configuration of nuclei), in general, have qualitatively different spectra. This is of particular importance for polyatomic molecules for which many more types of symmetry are possible than for diatomic molecules which have only the heteronuclear ($C_{\infty v}$) and homonuclear ($D_{\infty h}$) types. Group theory thus becomes important and allows one to classify the molecules according to different symmetry groups (point groups).

In the case of vibration spectra an essential step is the determination of the characteristic fundamental frequencies. The number of vibrational degrees of freedom for a molecule having N nuclei is 3N-6 (or 3N-5 if linear) which is also the number of normal modes of vibration or fundamental vibration frequencies. However complicated the vibrational motion of the molecule may be, it can be represented as a superposition of a number of these normal vibrations. These can be determined by the well-known methods of classical mechanics which will be, as in the diatomic molecules, a fair approximation to the quantum mechanical treatment. Considerable simplification in these methods can be brought about if a molecule has symmetry because then, also the normal vibrations and vibrational eigenfunctions have certain symmetry properties. Considerations of symmetry are of importance not only for the determination of normal vibrations and their nature but also for the description of higher vibrational levels, influence of anharmonicity, selection rules and interaction of rotation and vibration. Vibrations are classified as non-degenerate and degenerate. In non-degenerate vibrations the atoms move along straight lines and all are in phase. Such vibrations are either symmetrical or antisymmetrical with respect to the various symmetry operations according to whether they remain unchanged or reverse their direction. If they remain unchanged during all the symmetry operations they are called totally symmetric. If only certain symmetries are not preserved they are called non-totally symmetric. When several independent motions having the same frequency exist, the vibration is a degenerate vibration. Exact degeneracy is, in general, caused by symmetry. Degenerate vibrations may be symmetric or antisymmetric to some symmetry operations but other symmetry operations will cause the several degenerate vibrations to transform into each other. Brester (1923) was the first to apply symmetry considerations for the vibrations of polyatomic molecules. But since the discovery of Raman effect and the improved methods of infra-red technique, several workers e.g. Dennison, Wilson, Mulliken, Teller, Redlich, Howard, Rosenthal, Murphy and others have employed different methods based on these considerations (1931 onwards) . These methods of group theory have been applied to molecules of various symmetry types and also to asymmetric top molecules having nuclear symmetry e.g. H_2O, N_2O, Cl_2O etc. From the results tabulated it is now possible to obtain information leading to the classification of the normal vibrations of most molecules which are not too complex. Considerable progress has been achieved both in the development of the finer details of the theory due to quantum mechanics and its confirmation by the vibration spectra of the molecules as revealed jointly by Raman effect and infra-red absorption.

The superposition of rotation on vibration gives rise to the fine structure of infra-red and Raman vibration bands. The interaction between vibration and rotation is much stronger in polyatomic molecules than in diatomic ones and gives rise to different complications depending upon the particular rotator type to which the molecule belongs. Thus the following classification is particularly important for rotation spectra and the fine structure of the vibration spectra of polyatomic molecules : (1) Asymmetric rotators for which the three principal moments of inertia are all different; (2) Symmetric rotators for which two of the moments of inertia are equal and (3) Spherical tops for which all three principal moments of inertia are equal. Linear molecules form a special class of the symmetric tops for which one of the principal moments of inertia is zero or negligibly small while the other two are equal. The spectra of linear polyatomic molecules are fairly well understood by the extension of the theory of the diatomic molecule. The fine structure of the vibration spectra of other types of molecules is more complicated but has been worked out and although illustrated by a few examples offers a fairly interesting field for further study. When free rotation or slightly hindered rotation of one part of a molecule against the other is possible, further additional complications arise in the fine structure of the vibration bands. The analysis of fine structure whenever it is well resolved leads to very accurate and reliable information about the structure of particular molecules. From this structure can be accurately determined, the moments of inertia, internuclear distances and valence angles. This field of polyatomic molecular spectroscopy thus offers a very wide opportunity to theoretical as well as experimental work. Some of the most prominent workers in this field have been Placzek, Teller, Dennison, Jahn, J. R. Nielson, Herzberg, H. H. Nielson, Mecke, Wilson, T. Y. Wu, Sutherland, Redlich, Barker and Thompson (1934-onwards). Several linear molecules and a few molecules belonging to other rotator types including molecules with free rotation have been investigated, mostly in infra-red absorption. While quantum mechanical theory appears to be capable of meeting all such situations, experimental data are wanting in many cases because of the obvious difficulties connected with high resolution Raman and infra-red spectroscopy. Recent advances in both these fields are very encouraging. Specially designed Raman tubes with multiple reflection mirror attachments coupled with specially designed mercury arcs have enabled some very fine work to be done, e.g. by Stoicheff(29) (1954) in the rotational Raman spectrum of benzene and related molecules. Similarly, gratings of high resolving power and dispersion are being increasingly harnessed for infra-red work.

C. ROTATION SPECTRA AND MICROWAVES

Rotational constants and moments of inertia may also be obtained from pure rotation spectra as in the case of diatomic molecules, with perhaps more limitations. In all cases other than the linear symmetrical XY_2 molecule there will be two or more different internuclear distances. In such cases spectra of isotopic molecules are necessary and can be used assuming that the potential function and therefore the equilibrium internuclear distances are exactly the same in isotopic molecules. Rotational bands can be investigated by the conventional methods of far-infrared and Raman spectroscopy. But on account of the experimental difficulties complete data on only a few simpler molecules have been available so far. Of particular importance will be the rotational Raman spectra which are the only source of data for molecules having no dipole moment. For polar molecules, in the vapour state whose rotation energies lie in the microwave region, the quickly developing microwave spectroscopy promises to be of great value. Within this limited range it is unmatched by any other technique in precision, resolving power and dispersion as a tool for the determination of molecular structural constants. From the observed spectral frequencies moments of inertia are calculated. The various internuclear distances and bond angles can be uniquely determined by obtaining the moments of inertia of as many isotopic species of the molecule as the number of parameters involved in the calculations. Microwave methods are particularly significant for such determinations because of the large resolution and dispersion available. This enables the separation of rotational lines of the isotopic species sufficiently well. Now that elements enriched with any desired isotope are available from atomic piles, it is possible to increase the efficiency of the method almost to any extent so that it will be a powerful means for the evaluation of the molecular constants of polyatomic molecules. Another great advantage is that even very minute amounts of the isotopic species are usually enough to give spectral lines with an intensity sufficient for accurate measurement. At present microwave spectroscopy offers the only methods which can be employed for obtaining the spins, isotopic mass ratios, quadrupole moments and coupling constants, of the nuclei of radioactive elements of short life and low concentration which are important for nuclear physics.

D. ISOTOPE EFFECT.

Rotational isotope effect is of great value for the accurate determination of molecular structural constants. So also is the vibrational isotope effect for the determination and classification of vibrational frequencies of polyatomic molecules. Isotopic molecules have a common electronic structure. Hence the potential function is the same to a very high order of approximation. But on account of the difference in masses the vibrational frequencies are different and therefore additional equations for the force constants will be available. This is of decided value in polyatomic molecules because the number of constants in the most general quadratic potential function is usually larger than the number of fundamental frequencies. But with the help of the additional fundamental frequencies of the isotopic molecule or molecules, a sufficient number is generally obtained to determine all the constants. Secondly, it is possible to correlate the observed vibrational frequencies with the theoretical normal modes of a molecule. This is because the isotopic shift depends upon the amplitude which the atom in question has in the normal mode. Finally, in certain cases information about the geometrical structure of the molecule may be obtained, since the relative amplitude of vibration of a certain nucleus which can be replaced by an isotope depends on the geometrical arrangement of the nuclei. Particularly profitable has been the use of deuterium in investigations on polyatomic molecular spectra because it has twice the mass of hydrogen which it displaces and therefore gives rise to especially pronounced effects on the vibrational spectra of carbon compounds a large majority of which contain hydrogen. Theoretical considerations have led to the formulation of certain rules like the Order rule, the Ratio rule and the Product rule which have been of great value in this field.

E. PERTURBATIONS

(1) *Fermi and Coriolis interactions.*

Perturbations are very common in polyatomic spectra. They are produced by the mutual interaction of two states exactly as in diatomic molecules. These two states however, may belong to the same electronic state (e.g. the ground state) but different vibrational states. The perturbations may be classified according to their appearance into vibrational and rotational perturbations and according to their cause into Fermi and Coriolis perturbations. The shift of a vibrational level without rotation is always due to Fermi resonance i.e. to interaction with another vibrational level of the same species and lying close to the one considered. Among the numerous examples of this kind are the well-known Fermi multiplets discussed in detail by Dennison[30)] (1940) in the Raman spectra of CO_2 and H_2O and observed also in the electronic absorption and emission spectra of C_6H_6 by Ingold and collaborators[31)] (1936) and Asundi and Padhye[32)] (1949). A second type of vibrational perturbation is produced by Coriolis interaction. This concerns interaction between two vibrations belonging to different vibrational species.. Such vibrations cannot interact in the rotationless state but with increasing J values there will be an increasing repulsion of the rotational levels of the same J value if the two vibrations can have Coriolis interaction. The anomalously large l-type doubling found for the upper state $(2\nu_1+\nu_3+\nu_4)$of the C_2H_2 band and at $10{,}413\sigma$, is explained by Herzberg[33)] as a case of Coriolis perturbation. Other possible examples occur in the spectra of H_2O, H_2S, CH_4. Both Fermi and Coriolis interactions may also lead to typical rotational perturbations. Such cases have been found in the fine structure of the vibration spectrum of C_2H_2.

(2) *Rotational isomerism, Hindered Rotation, Resonance and Tunnel effects.*

The potential function of a given system of atoms may have more than one minimum. If these minima have different energy and shape they correspond to different isomers of the molecule considered. In general, such isomers can be chemically separated from one another (e.g. CH_3CN and CH_3NC). They can therefore be treated as different molecules altogether. If the barrier separating the minima however is very low, a transformation of one into the other can readily take place at ordinary temperatures so that such rotational isomers cannot be chemically separated. The existence of such isomers can be proved by their Raman and infra-red spectra. At ordinary temperature the spectra, e.g. in $C_2H_4Cl_2$, show several strong bands, a considerable number of which disappear at low temperatures (Mizushima and coworkers[31] 1934). If the potential minima are identical in height and shape exact resonance between the energy levels corresponding to the minima occur, leading to the splitting of the energy levels. Such cases are the non-planar molecules. They will have two identical potential minima corresponding to the two equilibrium positions of the nuclei that result from an inversion of all nuclei at the centre of mass. The energy levels corresponding to the two configurations are always in exact resonance and therefore in consequence of the tunnel effect a splitting into two energy levels takes place .A well-known but solitary example is the socalled inversion doublet in the symmetrical top pyramidal molecule NH_3 which was recognised by Dennison and Uhlenbeck, and observed first by the splitting of the individual lines of its pure rotation spectrum (Wright and Randall[35] 1933) and then by the direct measurement of the energy of the tunnel splitting by microwave methods (Cleeton and Williams[36] 1934). The inversion spectrum of NH_3 has since been studied in detail by microwave methods and has revealed the existence of interaction between inversion and rotation. Similarly in the case of certain slightly asymmetric top molecules e.g. CH_3OH, a study of their microwave spectral lines by Burkhand and Dennison[37] (1951) enables one to understand the phenomenon of internal rotation between OH and CH_3 groups in greater detail than it was possible with the conventional methods. Such a study extended to a sufficient number of isotopic species of the molecule should enable one to determine unequivocally its molecular structural parameters which are otherwise difficult to obtain.

F. ELECTRONIC SPECTRA

This is the field of molecular spectroscopy where not only experimental investigation but also theoretical development is still more or less in the exploratory stage. For several reasons the electronic spectra of polyatomic molecules are vastly more complex than those of diatomic molecules. Briefly stated, the complexity is due to the fact that the variety of vibrational and rotational frequencies associated with electronic transitions is greater than for diatomic molecules, the anharmonicity of vibrations does not give rise to the convergence of the levels but changes the vibrational structure in complicated ways particularly at large amplitudes and vibrations interact strongly and in various ways with rotation and among themselves so that the total structure of the band becomes very confused. Furthermore, an excited polyatomic molecule has more possibilities of dissociation and ionization than a diatomic one. This instability results in most of the bands being very often diffuse and sometimes continuous even in absorption. Consequently in emission, such bands are either very diffuse or completely wiped out. The result is that it has been very difficult to excite the emision sepctra of polyatomic molecules. Thus one source of locating a relatively larger number of electronic levels of the molecules is almost blocked. Nearly the same situation exists with regard to fluorescence spectra. Even in absorption the number of systems known for any particular molecule is very small. It is possible that in the vacuum far-ultra-violet region many more systems may be lying but work here has not been easy. Also from the experience already obtained , it is likely that Rydberg series of bands leading to ionisations of the molecule will be met with in this region. These will be valuable for other purposes than that of understanding the structure of electronic spectra.

Electronic states of poly-atomic molecules can be classified according to their multiplicity exactly as in atoms and diatomic molecules. Most molecules which are chemically stable have singlet terms in their ground states and may have singlet and triplet multiplicity in their excited states. If in the first approximation the selection rule holds that only states of the same multiplicity combine with each other, we expect in absorption mainly the occurrence of singlet terms. Further classification of electronic states is based upon symmetry properties similar to the classification of the vibrational frequencies. The designation of the electronic levels as of its vibrational modes is therefore done on symmetry properties which go with the symmetry group to which the molecule belongs. Exact wave mechanical calculations are too difficult to obtain but based on group-theoretical considerations, it is possible to derive selection rules for the electronic transitions, (Herzberg and Teller[38] 1933), and to predict the gross structure of the electronic bands obtained both in allowed transitions and in the so-called symmetry forbidden transitions (where the pure electronic selection rules break down due to excitation of molecular vibrations of appropriate symmetry). These together with the application of the Franck-Condon principle afford the theoretical basis on which the vibrational structure and intensity distribution in the electronic band systems of a given molecule may be understood.

(1) *Absorption Spectra.*

Examples of complete vibrational analysis of polyatomic electronic spectra are rather few. Those of rotational analysis are still more rare;

The review by Sponer[39] (1941) for absorption spectra in the visible and ultraviolet and that by Platt and Klevens[40] (1944) for absorption spectra of organic molecules in the vacuum ultra-violet are two of the reference articles available for workers in the field. Much work has been done since then but the general trend has been diverted mostly to the spectra of aromatic complex molecules e.g. benzene and substituted benzenes. Inspiration for this work came through the interpretation of the absorption spectrum of benzene around 2600A by Sponer, Nordheim, Sklar and Teller[41] (1939) following the theoretical calculation of the energy levels of benzene by Sklar[42] (1937). Although several other spectra have been interpreted on the lines on which the above spectrum of benzene was understood and although two more systems of benzene have been analysed, this is the only system which is unequivocally assigned to the predicted transition $A_{1g} \rightarrow B_{2u}$. A very comprehensive study of the benzene spectra (infra-red, Raman, electronic absorption, fluorescence at low and high pressure) as-well-as those of deuterated benzenes is that of Ingold and collaborators[31]. Another interesting line of work is that regarding the lowest triplet state in many of these aromatic ring molecules. Transition to this level from the ground level is doubly forbidden (spin and symmetry) but it is possible to obtain phosphorescence of the molecule (e.g. benzene, Lewis and Kasha[43] 1944) in a rigid glass-solution. This emission in benzene is a transition from the lowest triplet level to the ground A_{1g} state. Similar triplet states have been located in many other molecules by this technique. In many cases the weak absorption band corresponding to the phosphorescence band has also been observed.

(2) *Emission Spectra*

The emission spectra of polyatomic molecules have been observed in only a few cases. Usually, the molecule undergoes decomposition when it is excited by the methods used for excitation of diatomic molecules. In many cases molecular spectra of the fragments of the polyatomic molecule are obtained. Continuous emission spectra are also obtained but these do not give unequivocal evidence that they are due to the undissociated molecule. A systematic study of such continuous spectra including that of the spectra of the fragments is desirable. Discrete emission bands were first excited by Tesla discharge in flowing vapours of certain organic compounds by McVicker, Marsh and Stewart[44] (1923). In more recent years several attempts are being made to devise methods of excitation by which the emission spectra of polyatomic molecules could be obtained. Emission in benzene derivatives excited by electron impact and in the positive column of a specially designed discharge tube in the presence of rare gases has been studied by Schuler and collaborators[45]. The interpretation of the results obtained is not yet very clear. Continuous and in some case discrete bands provisionally attributed to a radical of the molecule are observed. Emission bands that correspond to the known absorption bands of the molecule have been obtained in benzene, toluene, aniline and several other organic aromatic molecules during the past few years by workers in my laboratory46). Very recently the so-called blue bands of benzaldehyde have been obtained with sufficient intensity and therfore in greater number under well determined conditions of vapour pressure and discharge (Robinson47) 1954). The large number of additional bands thus obtained enables one to prove the identity of the bands with the absorption bands of benzaldehyde. Considerable interest attaches to such investigations because of the possibility that they might lead ultimately to an enrichment of our information regarding the electronic states of polyatomic molecules.

V. CONCLUSION

Spectroscopic data are important and of considerable use, above all to the development of the theory of molecular structure and valency. But they have also been of value in many other directions such as the structure and properties of atomic nuclei, para-magnetism, collision processes, nature of the liquid and the solid states, determination of high temperatures, calculation of thermodynamic quantities, chemistry of free radicals, elementry chemical reactions in gases, chemiluminescence, photochemical primary processes, chemical equilibria, atomic heats of formation and related topics and several problems in astrophysics such as planetary atmospheres, comets, emission and absorption spectra of the earth's atmosphere, steller atmosphere and interstellar space.

Molecular spectroscopy has thus grown to be an ever-growing tree of knowledge whose fruits are available to seekers after truth in diverse ways. Some of its branches e.g. rotation and vibration bands of diatomic molecules are now more or less thoroughly familiar. Even in these branches new techniques like radio-frequency and microwaves and the development of high resolution and dispersion instruments like the echelle-plus-grating combination spectrographs, combined with the amazing developments which are taking place in experimental methods, are likely to unfold still deeper and finer aspects of knowledge. Such an expectation seems all the more certain in the case of rotation and vibration spectra of polyatomic molecules. Here we have had a glimpse of the splendour that is still to be uncovered. Theory tells us what we should expect to find in the task that it has set in this branch. The electronic bands of di-atomic molecules are well understood but our knowledge of the electronic structures of molecules is not as satisfactory as that of the atoms. The polyatomic molecules have practically still held from us the real meaning of their electronic spectra. In this branch of spectroscopy we have just felt the enormous magnitude of the task that spectroscopy is expected to do in the coming years. The feeling is similar to what one experiences on entering edifices of Karnataka architecture, for instance, a temple in *Halebeedu*[a] or the famous *Kailas*[b] cave at *Elura*[c]. Molecular spectroscopy has been the fundamental bedrock for quantum mechanics which in turn has supplied the inspiration that is necessary for exploration in the mysteries of nature. The vedic exhortation "*Parasparam bhāvayantaḥ sreyaḥ param avāpsyatha*"[d] finds one of its fullest illustrations here. To borrow our traditional analogy, molecular spectroscopy is to quantum mechanics what a *bhāshya* is to a *sootra*. The significance of spectroscopy is thus great and it pays to cultivate its study and research.

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SECTION OF CHEMISTRY

President :—Dr. A. C. Chatterji, D.Sc., Dr. Ing.

PRESIDENTIAL ADDRESS

PERIODIC PRECIPITATION

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INTRODUCTION

My first duty is to thank you most sincerely for the honour you have done me in electing me the President of this Section. I am thankful to the authorities of the Science Congress for this honour.

I take this opportunity to place before you a brief survey of the phenomenon of periodic precipitation widely known as Liesegang rings in which I have been interested for a long time.

DESCRIPTION OF THE RING FORMATION

Banded minerals like agate, chalcedony, onyx, cornelian etc. have been known from very early times. Their occurrence was supposed to be due to the periodic variation of one or the other internal or external factor or due to stratification at different periods. That it is possible to have banded structures, even when all the factors are constant was first pointed out by Liesegang.[39] in 1896. He saw, however, the importance of the phenomenon and suggested the close resemblance of the laboratory produced rings with bands in the naturally occurring minerals. The phenomenon is often named after its discoverer, Liesegang. The first observation of rings, however, must be ascribed to Lupton[40] although Ord[50] as early as 1869 obtained rings of Calcium carbonate in isinglass gel. Some say that this phenomenon was known to Runge[51] in 1855, who obtained stratified precipitation on papers.

Liesegang produced rings of silver chromate separated by clear spaces by diffusing silver nitrate into gelatin gel containing a little potassium dichromate, spread on a glass plate. He himself as well as many other workers after him have extended this work. Experiments have been carried out in test tubes containing gels, with one of the reacting electrolytes distributed uniformly in them as well as on plates, over which impregnated gels were spread. An aqueous solution of the other reactant is either allowed to diffuse from the top of the gel in test tubes or a drop of it is placed in the middle of the impregnated gel.[27]

Gels other than gelatin, such as agar-agar,[27] arsenate, ceric hydroxide etc. have also been used. Gore[21] prepared rings in uniform deposits of the phosphates of Cu, Al, Fe, Cr, Ni, Co, Ca and Ba, silicates of Al, Ca, Mn, borates of Ca and Ba, Calcium oxalate and ferric citrate instead of usual gelatin and agar-agar. Bhatnagar[24] and coworkers have suggested that rings in beetroots and even the stripes in Zebra are manifestation of the same process.

The periodic structures described by Liesegang were those in which rings were separated by clear spaces. At first this was the only type of rings observed. Dhar and Chatterji[17] have definitely established two types of banded structures, in one the rings are separated by clear spaces such as the original silver chromate rings in gelatin, and in the other there are bands in the otherwise continuous deposit consisting of alternate layers of rings of different colours, without any clear space between them. Such rings were also observed by Hatschek with CdS_2. Silver chloride in silicic acid, silver and mercuric iodides in agar-agar and nickel and cobalt ferrocyanides in gelatin also give the second type of rings.

Very recently Chatterji and Rastogi[7] have obtained rings of salts of rarer elements in gelatin and agar-agar. Here also two types of rings were observed as before.

As a result of the perusal of the vast amount of works on Liesegang rings, of which only a small portion has been cited above, it is abundantly clear that this phenomenon is of very general occurrence and it can be safely stated that all reactions giving rise to a precipitate can under suitable condition give rise to stratification. Attention was drawn to this for the first time by Dhar and Chatterji. Hedges[28] has also corroborated it. While Stern[57] says that this statement is hardly probable. Even he admits that an examination of the literature reveals that many compounds are capable of producing rings and this conveys the idea of the generality of the phenomenon.

The influence of the nature of the gel and its concentration, the electrolyte concentrations—both in the gel and the one diffused from the top-temperature and light, on ring formation has been investigated.

The nature of the gel and to some extent its concentration have a marked influence on ring formation. The gel also plays an important role in modifying the nature as well as the formation of the rings. It has been found that beautiful rings of selenium metal are produced in gelatin gel but this tendency to form stratification decreases as we pass on to agar-agar and finally no bands occur in the starch gel. Similar was the case with cerous salts and coper selenite. Silver tungstate in agar-agar gave structures of the first type while in starch gel structures of the second type were obtained. Thus the gel undoubtedly plays an important part in ring formation.[8]

In general the concentration of the reacting electrolytes have a distinct influence but in some cases the change in the strength of the electrolytes produces very little effect. Copper ferrocyanides rings in gelatin are not effected by a change in the concentration of the reacting electrolytes. It was also observed that the number of rings decreased with the decrease in the concentration of the diffusing electrolyte. Further, it was found that as diffusion proceeds the rings get generally separated, but in some cases opposite is the effect and the rings approach each other as diffusion proceeds[12] e.g. Zn, Ni & Co ferrocyanides and Ni & Zn, Fe cyanides, Ba & Hg(ous) vanadate, cerous oxalate rings in gelatin and chromium hydroxide, thallic oxide and uranyl carbonate in agar-agar. It has not been always found as Bradford claims that variation in the concentration of the electrolyte evenly distributed in the gel has a greater influence on the character of the rings than a change in the concentration of the diffusing electrolytes. A variation in the concentration of either of the reacting substances affects the character of the rings nearly to the same extent. In short the influence of the reacting substances are specific and does not depend on its position as assumed by Bradford.[9]

A change in the temperature increases the distances between two successive bands although fewer bands are formed.

It is not correct to say that the influence of light is not known. There is little doubt that light influences the formation of rhythmic precipitation in systems which are sensitive to light ; but various workers have reported contradictory results. It is, however, true that there may be systems that are not affected by light. The only effect of light observed in the very large number of experiments done by Chatterji and Rastogi show that the number of rings is increased. In the case of Liesegang rings of the second type, it has often been noticed that either none or very little band formation takes place in tubes kept in the dark, while beautiful distinct bands are to be found in similar tubes exposed to light.[11]

Oden and Köhler[47] found that light of short wave lengths was most effective but Isemura[34] states that visible light increases the number of bands and decreases their distance while the ultra violet light retards the formation of the rings. Kofman and also Miyamato[12] think ultra-violet light only decreases the width and spacing. Nikiforov and Lemeche[46] are of the opinion that the rings are directly proportional to light intensity.

It appears that light exerts its influence on the sol and so consequently, in general, more rings are formed in diffused day light than in the dark.

(1) *Theories of the Liesegang Rings*

Wilhelm Ostwald[63] was the first to give an explanation of the Liesegang phenomenon. It is based on the hypothesis that supersaturation is followed by precipitation. The theory supposes that when silver nitrate meets potassium dichromate, a precipitate is not formed immediately but the silver chromate remains in a highly supersaturated state. Precipitation does not take place until the 'metastable limit' is exceeded. When precipiate is formed a short distance behind the diffusion front, the silver chromate left in the solution diffuses towards the solid nuclei formed thus forming a clear space so that the diffusing electrolyte has to travel through this distance before the cycle is repeated. In this way the occurrence of the clear space is easily accounted for.

Here Ostwald has made the tacit assumption that the volume occupied by solid silver chromate in the gel is much less than the volume occupied by supersaturated solution of the same substance. It is well known that in a highly supersaturated solution of sodium and potassium acetate, ammonium nitrate, potassium and ammonium thiocyanates in aqueous solution and many organic non-aqueous supersaturated solutions, practically the whole mass solidifies on seeding or in other words, the volume occupied by the supersaturated solution is the same as that of the solid crystals imbeded in the solvent. Therefore the assumption of Ostwald to explain the clear space is not in agreement with the actual observations on the release of supersaturation.

Hatschek[29] has also criticised the supersaturation theory on the basis of ring formation even in presence of crystals of the sparingly soluble substances. This criticism has been overcome by supporters of the theory by stating that the surfaces of the planted crystals are not fresh but contaminated by the gel, hence they are unable to prevent supersaturation but Ghosh[25] has been able to obtain periodic precipitates of lead iodide, silver chromate and silver iodide in the presence of respective solid particles and in the complete absence of gel medium and he concludes that supersaturation does not lie at the basis of any satisfactory explanation of the Liesegang phenomenon. He also found that the precipitate at one stage was fine enough to show distinct Brownian movement. Thus Notboom's[18] argument that the surfaces are not clear but contaminated by the gel does not apply to these experiments as no gel existed here, as the solution was purely aqueous.

(2) *Ion-adsorption Theory of Bradford*

Bradford[2] postulates that the clear space between the rings is caused by the adsorption of the solute in the gel by finely divided precipitate in each ring. Hence the space between the rings is free from the solute. Here the adsorption of the inner liquid by the precipitate is an important factor. This is experimentally supported to some extent by photographs of strongly coloured solutions such as alkali chromates where a colourless zone appears immediately below the ring, showing that the chromate ion has been removed. Moreover ring formation in many cases seems to depend on crystal size. Silver chromate gives fine crystals in gelatin and hence rings are formed in this medium while it gives large crystals in agar with no rings.

The size of the particles can be varied according to the equation of von Weimarn :

$$N = K \frac{P}{L}$$

where P is the supersaturation, L is the solubility, K is a function of solvent viscosity as well as of the size and structure of the ions in solution and N is the dispersion co-efficient which is related to the mean magnitude of the single crystal in gm. molecules by the expression

$$Gm \times N = \text{Constant}$$

To produce a ring in a gel in which it does not ordinarily give one, N must be made large. Bands can be produced also by increasing P by the addition of highly charged ions or by diminishing L, the solubility by the addition of alcohol. For example, by adding varying amounts of citrate, silver chromate rings have been prepared in agar.

Hedges has pointed out, however, that the assumption of adsorption is not absolutely necessary. The inner liquid must diffuse against the incoming solution because of the concentration gradient, and this alone accounts for dilution under the ring. Adsorption can, of course, accelerate the diffusion process.

It has also been proposed that the clear spaces between the rings result from coulomb repulsion between the diffusing ions adsorbed on the precipitate and the remaining portion of the same ions which are still free.[4] In this model, precipitation can occur only when the distance between the last ring and the ions diffusing towards it has become great enough for repulsion to be negligible.[58] Some quantitative experimental evidence has been brought forward in support of this view.[16] But, although such coulomb repulsion undoubtedly exists (assuming that a preponderance of ions with the same charge are actually absorbed on the precipitate) the primary cause for the diffusion process is the difference in the concentration of the reacting ions.

THE COAGULATION THEORY OF DHAR AND CHATTERJI

It is unfortunate that the explanations of both Ostwald and Bradford leave the gel out of account. Ostwald takes the gel at best to influence the limit of supersaturation to some extent, while Bradford says it can affect the degree of dispersion of the precipitate and thus change its adsorbing power.

Moreover both these theories claim to explain the formation of rings only of the first type in which clear spaces between the rings appear. But as has been pointed out before there is another class of rings which consist of alternate bands of different colours with no free space between them. What gives bands of different colours in this otherwise continuous deposit, is difficult to explain from the above theories.

The theory advanced by Dhar and Chatterji (loc. cit.) takes into consideration the action of the gel and assumes that the sparingly soluble salt is at first in a colloidal condition due to the peptising influence of the sol. Owing to the high concentration of the diffusing electrolyte at the beginning, the quantity of the sparingly soluble salt formed is much in excess to that which the gel can hold in suspension and hence it coagulates, the process being further facilitated by the electrolytes present. The advancing layers of the diffusing electrolytes meet fresh quantity of the inner electrolyte and produce the sparingly soluble salt at first in the colloidal state. This colloidal sol is gradually coagulated and adsorbed by the solid precipitate of the sparingly soluble salt already formed and adheres to this solid and thus reinforces it, leaving a space through which the diffusing electrolyte has to pass to encounter a fresh region of inner electrolyte. The process of coagulation is also assisted by the product of the reaction which is an electrolyte. When the diffusing electrolyte passes into a fresh layer of the inner electrolyte, at first it forms a layer of colloidal sol of the sparingly soluble salt, which is no longer capable of being adsorbed by the original ring. The concentration of this sol increases and then it coagulates due to the limit being reached which the gel can hold in suspension. The presence of electrolytes facilitates coagulation and thus helps to form the second ring. The process repeats itself and we get a series of rings. Thus the formation of the first type of rings is explained.

In cases where coagulation of the sol cannot take place in presence of the solid matter or if the electrolyte concentration is not sufficient to make the sol unstable due to the adsorption by the precipitate of the electrolyte present which is the second product of the reaction, alternate layers of precipitated and colloidal sol of the same sparingly soluble salt are formed. These have usually different colours. This case is fundamentally different from the previous one already discussed.

On the basis of this theory, Liesegang rings can be divided into two classes (*a*) substances which do adsorb their own sols and produce a layer of precipitate in the form of a ring and (*b*) substances which do not adsorb their own sols and therefore give an alternation of coagulated and peptised layers having different colours. Case (*b*) has been considered from a different point of view also, *i.e.* that the soluble electrolyte formed in the reaction is absorbed by the precipitate. This lowers its concentration behind the precipitate and permits the stable peptised solution to exist. Evidences and criticism of this theory will be dealt on later.

THE DIFFUSION WAVE THEORY OF WO. OSTWALD

Another theory which has received attention is that of Wo. Ostwald.[64] It is based on the following assumptions:—

(*i*) Chemical reaction is necessary to produce rings, and moreover such reactions should be reversible ones, subject to equilibrium according to the Law of Mass Action.

(*ii*) In a system there must be at least three diffusion waves *i.e.* of the outer electrolyte, inner electrolyte and that of the soluble product of the reaction.

The fact that either rings may be destroyed by the subsequent introduction by diffusion of the electrolyte produced in the reaction or they may be produced from a continuous precipitate in a gel by the diffusion of the product of the reaction, is taken as supporting the above views.

The production of rings from a continuous precipitate can be very well explained by the coagulation theory and in fact Dhar and Mittra[19] have obtained rings of ferric, chromic and stannic hydroxides by the slow coagulation of the sols of these salts by diffusing KCl and $NaBrO_3$. We are of opinion that the precipitating influence of the diffusing electrolyte on the sparingly soluble salt distributed uniformly in the gel is sufficient to produce an initial layer of the precipitate. This layer adsorbs the uniformly distributed sparingly soluble salt from the neighbouring zone and this explains the clear space. Evidences in support of the adsorption of sols by precipitates and the relative account of the sparingly soluble salts in the ring and the clear spaces have been obtained to prove the coagulation theory.

Without going into details of the diffusion theory the following observations will point out its shortcomings:—

(*i*) Hedges and Henley[30] and Chatterji and Mukerjee (loc cit) and various other workers have shown that chemical reaction is not necessary for the production of the periodic precipitates.

(*ii*) Literature shows that beautiful bands of Barium sulphate, halides of silver, hydroxides of nickel, cobalt and iron[19]; gold, silver, mercury and selenium metals have been obtained. Here either reactions are complete or irreversible, hence the question of their shifting the equilibrium one way or the other does not arise.

(*iii*) Many workers (Hedges and Henley; Chatterji and Mukerji (loc. cit.), Dhar and Mittra and others) have produced rings of different sols by true coagulation process where only two diffusion waves are possible, but the theory requires at least three – the third one being very important – hence it has failed to explain all the experimental evidences.

Similar theories like that of Wo. Ostwald have been proposed by other workers[11] but as all of them are based on diffusion phenomenon or on some form of it and are only valid in the cases cited, they are not of general importance.

SURVEY OF THE ABOVE THEORIES

All the four theories postulate a critical condition as an essential factor in ring formation. Ostwald considers the metastable limit as the point at which the supersaturated solution precipitates. In Bradford's theory there is a critical concentration of the inner electrolyte, which occurs some distance after the medium has been impoverished of the electrolyte by adsorption by the precipitate. The outer electrolyte must diffuse until this critical concentration is reached before further precipitation takes place. In the coagulation theory of Dhar and Chatterji a critical concentration of the electrolyte is necessary for coagulation of the colloidal product. Wo. Ostwald diffusion theory also specifies a critical concentration of the electrolyte necessary for precipitation.

The other necessary factor contained in each theory provides for the mobilization of material. Both Ostwalds consider this factor to be diffusion, Dhar, Chatterji, and Bradford believe it to be adsorption.

4. IMPORTANCE OF THE CONDITION OF THE SPARINGLY SOLUBLE SALT IN THE GEL

From the above theories of Liesegang phenomenon, it is clear that it is extremely important to have as much information as possible about the condition of the sparingly soluble salt in the gel, its dispersion and its distribution between the rings and the clear spaces and the bands. It is also important to know if ions of the inner liquid or sols of the sparingly soluble salt are more adsorbed. Evidences on all these point have been obtained.

Freundlich[31] suggested that "the formation of periodic strata may be an instance of the coagulation by electrolytes of a suspended sol."

A large amount of work has been done on finding out the condition of silver chromate in gelatin and lead iodide in agar-agar by Williams and Muckenzie[65] and Bolam and his co-workers[4] Dhar and Chatterji.[18]

Both these salts give rings of the 1st type and are capable of forming complexes with one or the other of the reacting electrolytes. Moreover they are comparatively soluble in water. Bolam and his associates are of the opinion that both silver chromate and lead iodide are in the supersaturated condition, while Chatterji and Dhar suggest that over 60 per cent of the sparingly soluble salt is in a condition other than ionic. They measured their electrical conductivity and ionic concentration from e.m.f. determinations.

To arrive at a definite conclusion it is necessary to work with salts that are more insoluble and do not easily form complex compounds. Dhar and Chatterji have worked with silver bromide and silver iodide, and found that the percentage of the silver salt in gelatin in the ionic condition is very low. Recently Chatterji and Rastogi[11] have determined the condition of various sparingly soluble salts of silver and copper in gelatin by e.m.f. measurements. The salts studied were silver ferrocyanide, ferricyanide, thiosulphate and copper ferrocyanide, ferricyanide, borate, hydroxide and arsenate. In all these cases the percentage was less than 2 per cent. Only in the case of silver iodate about 18 per cent was present in the ionic condition. They[53] also studied the condition of the sparingly soluble salts of lead and zinc in gelatin sol. The salt examined were lead ferrocyanide, oxalate, phosphate, arsenate and iodide and zinc oxalate, chromate and selenite.

Here except lead iodide all others were less than 2 5 per cent in the ionic condition. In the case of lead iodide by e.m.f. method about 10 per cent was found to be in the ionic condition.

Hence only in the case of silver chromate and iodate and lead iodide is the percentage in the ionic condition more than the usual low value.

The mere fact that many sparingly soluble salts that give good rings are not found in the ionic state, whereas only a few salts like silver chromate, lead iodide and silver iodate show signs of existing to some extent in the ionic condition, causes considerable doubt on the general hypothesis of Ostwald that every sparingly soluble salt must be entirely in the supersaturated condition before ring formation. Moreover it may be interesting to compare the amounts of the sparingly soluble salts that are capable of remaining suspended in the gels with the amounts of the electrolytes that can form supersaturated solutions. While it has not been found possible to keep in the supersaturated state more than ten to twelve times the solubility limit in the case of sodium and potassium acetate, the following table gives the amount suspended in the gels which are many thousand times the solubility limits.

Silver chromate in gelatin ...	26·6 times
Lead chromate in gelatin ...	$3{\cdot}945 \times 10^5$ times
Silver chloride in gelatin ...	$5{\cdot}39 \times 10^2$ times
Silver bromide in gelatin ...	$1{\cdot}197 \times 10^4$ times
Silver iodide in gelatin ...	$6{\cdot}800 \times 10^5$ times
Mercuric sulphide in gelatin	$3\ 59 \times 10^{21}$ times
Silver sulphide in gelatin ...	$1{\cdot}037 \times 10^{11}$ times

It is rather difficult to assume such large quantities to be in the supersaturated condition.

ADSORPTION EXPERIMENTS

Bradford suggested that the clear space is due to the adsorption of the ions of the inner electrolyte, *e.g.* chromate by silver chromate and iodide by lead iodide whereas if the coagulation theory is correct then the adsorption of the sol should be much larger than that of the ions.

Experiments have been carried out both on the adsorption of constituent ions as well as of the sol by the sparingly soluble salts. The data obtained[12] have always confirmed that the percentage of adsorption in the case of sols by their own freshly prepared precipitate is exceedingly high whereas the adsorption of ions, if at all, is comparatively very low. In many cases such as Ag_2CrO_4 and K_2CrO_4, instead of any adsorption a dissolution of the precipitate results. So if adsorption is the cause of the clear space, it can easily be the adsorption of the sol rather than that of the ions, as it is extremely difficult to assume that chromate ions are adsorbed by silver chromate in the formation of silver chromate rings.

Moreover from adsorption experiments on sols it can be easily seen that the sols can be divided into two classes.

(a) *Sols that are adsorbed by their own precipitate*

To this class belongs the sulphides of arsenic and zinc, the hydroxides of nickel, cobalt and mercury, lead iodide and silver phosphate.

(b) *Sols that are not adsorbed by their precipitate*

To this class belongs the sulphides of silver, cadmium and antimony and manganese dioxide, mercuric oxide, mercuric iodide, silver iodide and silver ferrocyanide.

Mostly in the case of sols of the 1st. category we get rings separated by clear spaces whereas in the second category we get bands of the second type in the otherwise continuous deposit. For instance in the case of silver iodide, mercuric iodide, silver ferrocyanide and mercuric oxide alternate bands of different colours were produced, whereas rings separated by clear spaces were obtained in the case of lead iodide, silver phosphate and nickel hydroxide which adsorb their own sol.

Thus combining the two experimental facts, we clearly see that the salts which give rise to the first type of structures have a marked tendency to adsorb their own sol, while the salts giving the second type of rings instead of adsorbing their own sol pass into the sol. themselves.

DISTRIBUTION OF THE SPARINGLY SOLUBLE SALT IN THE RINGS AND THE CLEAR SPACES

According to the coagulation theory, in the first type of rings given by lead iodide in agar, a large amount of the precipitate should be present in the ring in comparison to the clear spaces, whereas in the second type of rings the amounts of the sparingly soluble salts in the bands of different colours in the otherwise continuous deposit should be very nearly the same.

Twenty different types of banded structures were analysed and the amount of sparingly soluble salt per gm. of gel present in rings was many times more than that in the clear spaces. But, in the cases of AgCl and AgI bands in the otherwise continuous deposits, the quantities present in the two adjacent bands of different colours were almost the same.

It may be argued that in the second type of rings after the release of supersaturation, the clear space is saturated with the sparingly soluble substance, or on the other hand, according to the adsorption theory the incomplete or partial adsorption of the solute by the precipitate may leave some of it near the precipitate to produce scanty deposits instead of complete absence of the sparingly soluble salt. Hence two consecutive rings will not be separated by absolutely clear spaces, but these clear spaces will be contaminated more or less by the sparingly soluble salts. The net result will be that the amount of the sparingly soluble salt per gram of gel in alternate bands will not be equal, but it will vary as in the case of rings separated by clear spaces. But this is not actually the case, the alternate bands contain almost equal amounts of the sparingly soluble salts. The following table will make the point clear.

PbI_2 RINGS (SEPARATED BY CLEAR SPACES) IN AGAR-AGAR

Distribution of lead as $PbSO_4$ in rings and clear spaces

No	Ring or clear space	Wt. per gm of the gel	Relative amount of per gm. of the gel
1.	Ring ...	... 0·02268	4·08
2.	Ring ...	... 0·03957	7·00
3.	Ring ...	... 0·04820	8·70
4.	Clear space	... 0·00555	1·00
5.	Clear space	... 0·00554	1·00

SILVER IODIDE BANDS (IN THE OTHERWISE CONTINUOUS DEPOSIT) IN AGAR-AGAR

Distribution of silver as AgI in differently coloured adjacent bands

No.	Band	Wt. per gm of the gel	Relative amount of per gm. of the gel
1.	Yellowish white ...	0046	1·00
2.	Grey ...	... ·0051	1·10
3.	Yellowish white ...	·0047	1·02
4.	Grey ...	... ·0050	1·08

The above results are typical but in the case of copper arsenate rings separated by clear spaces, the ratio is very high between the rings and the clear spaces (75 : 1) [34] The above results entirely corroborate the coagulation theory. The other theories are unable to explain the occurrence of Liesegang rings of the second type with nearly equal distribution of the salt between two adjacent bands in the otherwise continuous deposit.

SUPERSATURATION AND THE METASTABLE LIMIT

Inspite of the above evidences in favour of the existence of the sparingly soluble salt in the colloidal state ; it was thought necessary to study supersaturation in a detailed manner.

The first observation of Wilhelm Ostwald postulated in the absence of experimental evidence was that precipitation occurred when the solution became highly supersaturated. The corresponding concentration at which crystals formed even in the absence of solid phase was regarded as the metastable limit. The ion product at that concentration was called the supersaturation product.[43]

Some experimental evidence has been put forward in support of this by citing the case of silver chromate and PbI_2 in gelatin on the basis of observations by Bolam. The amount of lead that can remain in supersaturated condition in about 1·2 per cent agar was found by Bolam to be 36 per cent more than the amount required to produce saturated solution in water. But as has been pointed out in the case of more insoluble salts such as lead chromate, silver bromide, silver iodide etc. ; many thousand times the quantity of the salt required to produce saturation remain in solution. It appears extremely doubtful if such large amounts of the salt can remain in the supersaturated condition simply because gelatin and agar have been added. During our course of study of supersaturated solution of electrolyte like $Ba(NO_3)_2$, KNO_3, $AgNO_3$ etc., we have failed to note such remarkable property of gelatin, agar or starch towards increasing the degree of supersaturation by any considerable amount. Hence the claim of Bolam and Stern that the supersaturated solution is formed in the gel of highly insoluble salts is not confirmed by experimental facts.

Let us now examine the evidence in favour of the existence of a 'metastable region' and a labile range.

Ostwald[46] first suggested that below the saturation temperature there is first a 'metastable region' in which no crystals are formed spontaneously. A metastable boundary divides this from the labile range of temperature in which crystallisation necessarily occurs sooner or later spontaneously. Several workers[35] claim the existence of metastable boundary.

It appears that probably some changes in the molecular state occur at the saturation and the so-called labile temperatures, and these changes would be exhibited by sudden changes in the physical properties of the cooling system. From the researches of a number of workers on the study of physical properties such as freezing point[6], electrical conductivity[31] viscosity[40] specific gravity, specific heats, heats of solution[5] and dilatation[12], it appears, however, that no sudden changes occur. However, the idea first put forward by Ostwald of metastable and labile condition can be explained satisfactorily by an idea put forward by de Coppet[20] and developed by Tamman.[60]

SUPERSATURATION IN AQUEOUS SOLUTIONS

A large amount of work on supersaturation has been undertaken at Lucknow both in aqueous and non-aqueous solutions with a view to study supersaturated solutions and to find out the laws governing crystallisation from these solutions. Moreover a suggestion often put forward[8] that there may not be much difference in the properties of highly supersaturated solutions and dilute colloids, requires careful scrutiny.

Besides, if it is even proved that the sparingly soluble substance remains in the colloidal state, its stability should depend as suggested by Fajans and Mukerjee[21] upon the adsorption of the constituent ions. This adsorption is due to lattice forces and it may be of interest to know the mechanism of growth of lattice and to find a relation between growth and adsorption.

To begin with, the above problem has been tackled by studying the tendency of spontaneous crystallisation of various supersaturated aqueous solutions and dependence of this tendency on any of the properties of the system concerned. Dilatation, viscosity, vapour pressure and electrical conductivity of supersaturated aqueous solutions have been studied.[13]

Relative supersaturation of more than forty different substances have been studied in water, both electrolytes and non-electrolytes. As a result of this investigation substances have been divided into three categories. First in which spontaneous crystallisation occurs at almost the same temperature irrespective of the amount of heating during and after preparation of the solution. To the second category belong substances in which the temperature of spontaneous crystallisation in general, decreases with the amount of heating. In fact nearly all the substances which crystallise out spontaneously belong to this group. The first category appears to be an exception rather than a rule. In the third category are included the substances in which spontaneous crystallisation does not occur easily. They give very viscous solutions and probably do not crystallise out due to viscosity.

It has been found in the case of the first two categories that if T_S denotes the saturation temperature and T the temperature of first spontaneous crystallisation and λ the heat of solution at ordinary temperature then

$$(T_S - T)\,\lambda = C \quad \text{(a constant)} \quad . \; . \; . \; . \quad 1$$

The above equation has been derived from the theory of Jones and Partington[17] in the following form :

$$(T_s - T)\,\lambda = \frac{2\sigma M}{\rho} \cdot \frac{T_s}{r}$$

assuming T_s/r to be constant equation (2) leads to

$$(T_s - T)\,\lambda = \frac{K\sigma M}{\rho} = K\sigma V_m$$

$$\text{ie}\ (T_s - T)\,\lambda \propto \sigma V_m$$

$$\text{or}\ (T_s - T)\,\lambda/\sigma V_m = \text{constant (K)}$$

The value of this constant has been found to be 1.3 in a number of cases, this proves that T_s/r is a constant in these cases.

From the relationship

$$(T_s - T)\,\lambda/\sigma V_m = 2T_s/r$$

r can be calculated by taking the left hand side to be 1.3, so $\frac{2T_s}{r} = 1.3$. This gives a new method for estimating the size of the stable crystal nucleus.

From equation (2) we can also easily get that r $(T_s - T)$ = constant, which shows that the radius of the stable crystal nucleus varies hyperbolically with the degree of supersaturation as measured in terms of $(T_s - T)$. In other words, it means that the stability of a supersaturated solution varies hyperbolically with the degree of supersaturation. On this basis the hyperbolic energy-$(T_s - T)$ diagrams obtained by Young and others[68] have been easily explained. Ostwald's conception of metastable and labile region has also been explained on this basis.

From our viscosity measurements of about thirty new supersaturated solutions, no discontinuity has been observed at the supersaturated temperature.

The variation of viscosity with temperature has been examined in details. The simple equation of Andrade[1] $\eta = Ae^{B/T}$ has been found to be of very general application, specially when the viscosity is not very high.

In addition to this property, conductivity of a large number of systems has been studied, but in no case a discontinuity in the specific conductivity-concentration curve has been observed.

As a result of these studies, we are of the opinion that supersaturated solutions are unstable and that there is no molecular change when the solution passes from the saturated into supersaturated condition. There is no difference between metastable and labile state within the supersaturated condition. The hyperbolic nature of the variation of stability with supersaturation can explain the ideas of Ostwald very clearly. Moreover, there is no evidence of any colloid formation with highly supersaturated solution and further in no case we have succeeded in getting supersaturation beyond 10 to 12 times the ordinary solubility.

SUPERSATURATION IN NON-AQUEOUS SOLUTIONS

The above studies have been extended to supersaturated non-aqueous solutions.[14]

The viscosity of a fairly large number of systems of non-electrolytes in non-aqueous solvents has been studied at various temperatures. It has been shown that the simple Andrade equation is applicable to most of the systems here also. The deviations can be explained by Rabinovich's solvate hypothesis and depolymerisation theory of Appleby.

Here also we have noticed the same three categories of solutions. In the first category the temperature of spontaneous crystallisation remains constant irrespective of heating effect, in the second category T_s decreases on repeated heating. In the third category the supersaturation is not released even on rapid shaking. In fact all solutions which dissolve to give highly viscous solutions belong to this category.

In this case also the radius of stable crystal nucleus has been calculated to be 10^{-6} cm. This value is in good agreement with the value found by Tamman and Gronow.[61]

According to Richards[55] the effect of heating is due to the adsorption of the solute by the adsorbates. The adsorbed molecules go into solution on heating and thus the adsorbed oriented molecules are destroyed and are no longer able to induce crystallisation. This is confirmed to some extent by the fact that repeated filtration removes dust particles which act as adsorbate and so increase the degree of supersaturation.

Here it was found that instead of $(T_s - T)\,\lambda$ remaining constant, the following two modified equations hold good.

$$(T_s - T)\ L_F f = \text{constant} \qquad \ldots\ldots\ 3$$

$$(T_s - T)\ L_F f = \frac{2\sigma M}{f\rho r}\, T_s \qquad \ldots\ldots\ 4$$

Where L_f is the latent heat of fusion and f is the effect due to difference of internal pressure. The above relations have been derived from the equation of Mortimer[14]

$$\ln Sx = f\,\frac{L_F}{R}\left(\frac{1}{T_m} - \frac{1}{T}\right)$$

EFFECT OF FOREIGN SUBSTANCES ON THE LIMITS OF SUPERSATURATION

In the supersaturation theory of Liesegang rings, it has been repeatedly suggested that the presence of gel is inducive of increasing the supersaturation. We have studied the effect of foreign substances on the limits of supersaturation as measured by $(T_s - T)$ in the case of potassium chloride, bromide and chlorate and thallium sulphate.[15] Effect of a larger number of electrolytes ; non-electrolytes including surface active substances, dyes and colloids have been studied. Inorganic salts do not affect the supersaturation limit but surface active substances decrease the limit of supersaturation. Dyes, inspite of the fact that they are colloidal in nature, do not reduce the limit, other colloidal particles such as V_2O_5, Colloidal Sb, Co, Cr.As_2S_3 CdS and agar do not sensibly affect the limit of supersaturation. For a colloidal particle to act as nucleus it is essential that the solute should be capable of being adsorbed on it and the size of the particle should be greater than the critical value. Probably these conditions are not satisfied by most of the colloids.

Hence there appears to be no justification to assume that the very large amount of the sparingly soluble salts that remain suspended in the gel, when Liesegang rings are formed are in the supersaturated condition on account of the gel being capable of increasing the supersaturation.

KINETICS OF CRYSTALLISATION

Kinetics of crystallisation in supersaturated solutions has been investigated both from the theoretical and experimental view points.[56] The kinetics of nucleation in supersaturated solution has been theoretically treated and Frenkel's[72] theory of nucleation in melts has been extended to supersaturated solution. The rate of nucleation has been given* by the following expression

$$R = C_0{}^{-\alpha/3kT}\left\{\Delta u + \frac{\alpha}{3}\left[\frac{2}{3}\,\frac{\alpha' T_s}{L_s(T_s - T)}\right]^2\right\} \quad . \; . \; . \quad 5$$

which yields the following expression for the maximum rate

$$R\ \max = C_0{}^{-\Delta u/kT_{max}}$$

The following equation gives the value of $x(T_s/T_{max})$

$$\frac{(x-1)^3}{x^2(3-x)} = \frac{u}{27}\cdot\frac{\alpha^3}{L_s{}^2}\cdot\frac{1}{\Delta u} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad 6$$

The values of 'x' calculated from the above expression have been compared with the results found by Chatterji and Bose (loc. cit) and show satisfactory agreement.

CRYSTAL GROWTH

Similarly, the kinetics of linear crystallisation has also been treated[71] The theoretical treatment of Volmer and Morder[72] and Frenkel has been extended to include the case of supersaturated solutions. Accordingly the rate of linear crystal growth in supersaturated solution is found to be

$$I = C_0{}^{-1/kT}[\Delta u' + B/T_s - T] \quad . \; . \; . \; . \; . \; . \; . \; . \; . \quad 7$$

where C is a constant and $B = \frac{l'' T_s}{\lambda'}$

An expression for maximum linear crystallisation velocity has been deduced and is as follows:

$$I_{max} = Ce^{-\Delta u'/k(2T - T_s)} \quad . \; . \; . \; . \; . \; . \; . \; . \quad 7a$$

Linear crystallisation velocity of solutes in twenty seven systems has been experimentally determined at different degrees of supersaturation. An experimental method adaptable to supersaturated solution has been devised. Most of the data could be explained on the basis of Volmer Frenkel theory.

The thermodynamic theory cannot give an estimate of the constant C of the equation 7a. Although Reiss[70] has tried to deduce expression for the constant from statistical consideration, yet it is not possible to have an exact estimate because of certain factors which cannot be evaluated. One reason for low value of velocity in certain cases may be ascribed to the fact that the crystals which grow are not perfect and their imperfections provide the steps required making two dimensional nucleation unnecessary. Thus, the low value of velocity may be due to the absence of dislocations in the surface or to the presence of so many that the mean distance between them is much smaller than the crystal nucleus. Burton, Cabrea and Frank[69] have shown that the latter alternative is not possible. Reiss and La Mer[71] have theoretically solved the problem of diffusion which involves moving boundaries. They have deduced expressions for the case when the flux of material through any surface in the diffusional field is considerably, greater than the rate of change of concentration on that surface and *vice versa*. The interpretation of the results on the basis of such a procedure may yield interesting results.

(6) THERMODYNAMICS OF SUPERSATURATED SOLUTION

INFLUENCE OF INTERNAL PRESSURE ON THE RELEASE OF SUPERSATURATION

With a view to determine the effect of internal pressure on the release of supersaturation, the limits of supersaturation of seventeen liquid-liquid systems has been studied.

It has been observed that equations applicable to solid-liquid systems are not applicable to liquid-liquid systems.

A very important aspect of supersaturation of liquid-liquid system that attracted our attention is that the interfacial tension at least in bulk between the two liquids can be easily found out either experimentally or it can be calculated from Antonow's rule and hence any equation based on interfacial tension can be verified.

Basing their calculations on the theory of Hildebrand[33] and Scatchard ; Black, Jones and Taylor gave the expression :

$$RT \ln\frac{\alpha_1}{N_1} = V_1 \Big[\left(\frac{\delta E_1}{V_1}\right)^{\frac{1}{2}} \quad \left(\frac{\delta E_2}{V_2}\right)^{\frac{1}{2}}$$

Where $\alpha_1 = \frac{f}{f_0}$, f being the fugacity of the solute in solution and f_0 the fugacity of pure solute and N_1 and V_1 denote the molar concentration and molar volume of the solute, $\frac{\delta E_1}{V_1}$ and $\frac{\delta E_2}{V_2}$ represent the internal pressures. By assuming α_1 to be unity for dilute solutions and combining the above equations with Thompson's, one gets by suitable modifications and assumptions

$$T_s - T = \frac{2\sigma T_s}{\left[\left(\frac{\delta E_1}{V_1}\right)^{\frac{1}{2}} - \left(\frac{\delta E_2}{V_2}\right)^{\frac{1}{2}}\right] r}$$

Equation (8) has been tested and the values of $T_s - T$ obtained from the above equation are in fair agreement with the experimental results.[26]

FREE ENERGY BARRIER OF NUCLEI FORMATION

Ostwald put forth the concept of metastable state to describe the behaviour of supercooled liquids. This idea of his has been utilised to explain the Liesegang rings and therefore it is necessary to examine it from thermodynamic considerations. A thermodynamic system at a specified temperature is in a metastable condition if all small isothermal changes of its independent thermodynamical variables result in an increase in its free energy, whilst certain large isothermal changes in these variables can bring about a state with lower free energy.

The idea of metastability by definition requires that there be states of higher free energy than the metastable state along all possible routes between the metastable and stable states of a thermodynamic system. These intermediate states may be said to give rise to free energy barriers impending the transformation of the metastable state into the stable state. A supersaturated solution in crystallising out must pass through intermediate states having higher free energy than the solute in solution. In the light of above conceptions spontaneous crystallisation may be interpreted as the result of random accumulation of sufficient free energy for the solute molecules to pass over the energy barrier simply by thermal fluctuation.

It is assumed that crystallisation occurs in two steps ; first crystal nuclei form and then these nuclei grow into larger crystals. Hence there will be two types of barriers corresponding to nuclei formation and crystal growth.

These energy barriers are believed to be determined as follows :

(1) The free energy barrier to crystal nuclei formation arises essentially because the solubility of small particles is greater than the larger crystals. Thus in any supersaturated solution, crystals smaller than a certain size are unstable, so that in order to form a stable nucleus one must first form crystallites having higher free energy than the same amount in the solution phase.

(2) The free energy barrier to crystal growth on the other hand is simply that which prevents the movements of molecules at a crystal liquid interface from a liquid like position to a crystal like position.

By taking the above assumptions into consideration the following equation has been calculated[16] for the free energy barrier of nuclei formation from supersaturated solutions.

$$F_{max} = \frac{32\sigma^3}{fL_f^2}\left(\frac{T_s}{T_s - 1}\right)^2 \quad . \; . \; . \; . \; . \; . \; . \; . \; . \quad 9$$

The above equation can be compared to the equation obtained by Kauzmann[18] applicable to melts, which is given below :

$$F_{max} = \frac{32\sigma^3}{H^2}\left(\frac{T_m}{T_m - 1}\right)^2$$

Here H is the heat of fusion per c.c.

Experimentally observed supersaturated limits found out by Chatterji and Bose in non-electrolytes dissolved in organic solvents and supercooling in the case of melts observed by Rastogi (thesis, Lucknow University, 1952) have been used to calculate the free energy barrier of nucleus formation which is ultimately responsible for the release of supersaturation. It has been found that both in the case of solutions as well as in melts, the maximum free energy is of the same order i.e. 10^6 Cal. per gm. mol.

An attempt to apply these to sparingly soluble salt solution in gelatin and agar-agar did not meet with success, hence it is extremely doubtful if equations applicable to supersaturated solutions are also applicable to sols. But it must be pointed out that it does not imply that crystallisation must necessarily occur when F_{max} is crossed, since other factors are also involved in crystal nuclei formation.

THE DIFFUSION EQUATION AND ALSO ITS WAVE MECHANICAL TREATMENT

Shortly after the discovery of Liesegang ring, Morse and Pierce[45] carried out a calculation to determine the supersaturated product H. Ficks Law of diffusion for ions was used. From the equation they deduced that $x/\sqrt{t}$ must be constant. Experiments confirm this conclusion and therefore the supersaturated product H has been taken to be constant.

van Hook[62] had deduced this relation $x/\sqrt{t}$ = Const. without assuming the existence of a supersaturated product. Recently Wagner[67] has shown that the above relation is a necessary consequence of the diffusion equations and that it holds true even in the case of continuous precipitation ; the periodic interruptions may be regarded as small perturbations of the general diffusion process. He also[67] derived an equation for the distance between successive rings which agrees in general with the experimental facts.

Shemyakin and coworkers[59] assuming that the wave equation of de Broglie and Schrödinger can be applied to the average motion of the diffusing particles, treated the phenomenon of Liesegang rings as a consequence of wave concept of mechanical product. They deduced a number of equations involving the distance between the rings and the viscosity of diffusion and verified these equations.

However, it may be questioned if these equations are not applicable to the sparingly soluble salt when this happens to be in a condition other than ionic. The diffusion will certainly control the amount of the salt in a given volume and would thus produce condition where a sol may or may not be coagulated due to the limit of peptisation been reached.

Moreover a large amount of work has accumulated that shows that the supersaturation product H is not constant but variable.

CONCLUSIONS

A large amount of work on ring formation of both common and rarer metal salts in various gel reveal the fact that there are two kinds of Liesegang rings, in one, a layer of precipitate is followed by a clear zone and in the other, a band of coagulated mass by a zone of peptised sol.

We are of the opinion that the sparingly soluble salts which are capable of adsorbing their sols belong to the first type and in the other, are included the substances which do not adsorb their own sols. Hence it may be concluded that the amount of the sparingly soluble salt per gram of the gel present in the first type of the rings will be unequal and should vary widely, whereas in the adjacent bands of the second type of structures, the amount of the salt will almost be equal and this has been found to be true experimentally. Therefore it is clearly seen that coagulation theory correctly predicts the nature and the distribution of the sparingly soluble salt in both types of the banded structures.

A most striking evidence in support of the above argument is offered by the adsorption experiments of the sols and their constituent ions by the respective sparingly soluble salts in the course of their formation.

It has been found that salts like silver and lead chromates, ferric hydroxyde, arsenious sulphide, silver and lead phosphates, lead iodide etc., have a marked tendency to adsorb their own sols and these are the salts that form Liesegang rings of the first type in which rings are separated by clear spaces.

On the other hand sols of antimony and cadmium sulphides, manganese dioxide, silver and mercuric iodides, are not adsorbed by their respective precipitates but have a tendency to pass readily into the colloidal condition when shaken in presence of the sols and these substances give rings of the second type in which bands usually of different colours in the otherwise continuous precipitate are formed.

The results on the adsorption of the constituent ions show that the percentage adsorbed is very low and does not very often exceed more than 10 per cent which is negligible in comparison to almost 100 per cent adsorption with many sols. Hence adsorption of the constituent ions cannot play a dominant role in ring formation.

A large amount of work has been undertaken on supersaturation of both electrolytes and non-electrolytes in aqueous and non-aqueous solvents.

Relations and conditions governing the release of supersaturation based on mathematical calculations have been obtained in the case of pure supersaturated solutions, but it is extremely doubtful if these relations are applicable to the so-called solutions of the sparingly soluble salts when formed in presence of the gel

Moreover, evidence has been brought forward in the case of a large number of sparingly soluble salts that when they are formed in presence of the gel they are not in the ionic state, by carrying out a large amount of conductometric and potentiometric measurements.

Here except silver chromate, silver iodate and lead iodide which show evidence of existence to some extent in the ionic condition, a very large number of the salts like, silver chloride, bromide and iodide, lead ferrocyanide, phosphate, oxalate, arsenate and zinc oxalate, chromate and selinite, were found to be less than 2 5 per cent in the ionic condition.

The mere fact that many sparingly soluble salts that give good rings are not found in the ionic state whereas only a few salts show signs of existence to some extent in the ionic condition causes considerable doubt to the general hypothesis of Ostwald that every sparingly soluble salt must be entirely in the supersaturated condition before ring formation.

While it is not possible to produce supersaturation of any soluble salt which may contain more than 10 to 12 times the solubility limits, it has been observed that in the cases of sparingly soluble salts that give Liesegang rings many times this number (often exceeding 10^1 times) can be easily retained in the gel. It is rather difficult to assume that such large quantities of the sparingly soluble salt should remain in supersaturated condition due to the presence of the gel. Actual experimental work on the effect of foreign substance such as colloidal solutions of V_2O_5, Sb, Co, As_2S_3, CdS, agar-agar, dyes and many electrolytes and on-electrolytes on supersaturated solutions have been carried out. Inorganic soluble salts and many colloids including dyes and agar-agar do not sensibly affect the limit of supersaturation, but surface active substance decreases the limit of supersaturation instead of increasing it.

Hence there appears to be no justification to assume that the very large amounts of the sparingly soluble salts that remain suspended in the gel are in a supersaturated condition.

Summing up it is observed that the experimental evidences obtained here clearly explain all the important aspects of Liesegang ring formation and the results support the coagulation theory of Dhar & Chatterji.

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SECTION OF BOTANY

President :—DR. J. C. SEN GUPTA, M.Sc., D. Phil. Nat.

PRESIDENTIAL ADDRESS

CONTROL OF FLOWER INITIATION IN PLANTS

An increase in crop production to meet the need of the ever increasing population, is a problem of great importance to the future of India, and the world also. This can be achieved by a number of ways ; one of the very significant possibilities is the control of the vegetative period and the onset of reproduction of plants. This moment may be opportune to make a stock-taking of the available information in this field of research and I have chosen as the subject of my address today, "Control of flower initiation in plants".

EXTERNAL AND INTERNAL CONDITIONS

The physiological basis of the environmental control of flowering was probably laid by Sachs long back in 1865 when he introduced the concept of organ forming substances which are formed from the assimilation products and then transported to the different parts. It was suggested that for the production of flower forming substance a higher light intensity is necessary than for the formation of root and shoot forming substances. Experimental evidence was produced to show that leaves in light produced definite "flower forming" substances (Blühstoffe). These specific substances may also be accumulated in storage organs.

A closer analysis of the conditions, internal and external, determining vegetative growth and reproduction respectively dates back from the researches of Klebs. Between 1889 and 1904 he published researches on the influence of different environmental conditions on the course of development, and in 1903 he published his observations on the condition for the reproduction in algae and fungi which has become classical[39]. Between the year 1900 and 1918 he published his valuable contribution to our knowledge of the effect of conditions in determining the course of development in higher plants. His main thesis is that it should be possible to separate the factors governing plant growth and development and then to expose plants to optimal doses of these factors under artificial experimental conditions, thereby making it possible to control and direct the courses of growth and development. Klebs found in his investigations on *Sempervivum* (1918) that formation of reproductive organs results when the rate of production of carbohydrate is high compared with the rate of intake of water and mineral nutrients, while vegetative growth is furthered by a lower rate of production of carbohydrate in proportion to the supply of water and nutrient salts. He also observed that the process of formation of inflorescence proceeds in three clearly separable phases, which he called the onset of the ripe-to-flower condition, the formation of the flower primordia, and the development of the inflorescence.

Before the attainment of the ripeness-to-flower stage, no change in external factors can induce flower initiation ; this thus corresponds to the stage of puberty in animals. Ripeness-to-flower is not recognisable morphologically ; on the other hand, the initiation of flower primordia and the formation of flowers and inflorescences are visible.

The first concept has been further elaborated in terms of carbohydrate, nitrogen ratio by Kraus and Kraybill[43] and several other investigators. It would appear on the balance of evidence that the ratio is very often a consequence rather than a cause of flowering. The second concept finds its logical outcome in the phasic development theories of the Soviet physiologists.

During the last three decades two environmental factors have been relatively carefully and intensively investigated in respect to their importance in the initiation of flowering, viz. temperature, and day length. Growth hormones in plants were also discovered during this period. Development in the physiology of flowering have thus been determined by three recent researches: first Gassner's work in 1918[21] on the effect of temperature during germination on the flowering responses of spring and winter cereals ; secondly the discovery by Garner and Allard[19] of the importance of the duration of alternate light and dark periods in controlling flowering ; and thirdly the isolation by Went[100] of plant hormones controlling extension growth and meristematic activity. Thus the phenomena of vernalization and photoperiodism were discovered and attention drawn to hormonal regulation of growth in plants.

Vernalization

After the experiments on the effect of presowing treatments of winter cereals in 1929 and the formulation of the theory of phasic development of plants by Lysenko, several investigations have been carried out on the various aspects of vernalization. Some of the important findings on the fundamentals of the process by Gregory and co-workers are the following : (*i*) That the vernalization effect is localised in the embryo itself and is entirely independent of the changes in the endosperm or aleurone layer which may take place during germination[28]. (*ii*) That vernalization can be reversed (devernalisation) : (*a*) by high temperature though the devernalized grains can be revernalized by exposure to a second period of low temperature[27, 74]. (*b*) by drying down the vernalized grains for periods longer than 6 weeks[28]. (*iii*) That the low temperature effect is completely inhibited in the absence of oxygen, which suggested that low temperature and not mere inhibition of growth is the essential factor in vernalization[29]. (*iv*) That the excised embryo of rye when supplied with nutrient salts and glucose responded to vernalization in the same manner as the whole grains and to a comparable degree[26]. (*v*) That the isolated stem apex of the embryo if supplied with sugar and subjected to low temperature regenerates the whole plant which shows itself to have been vernalized[73]. (*vi*) That the low temperature effects associated with vernalization can be obtained in ripening seeds while they are still attached to the mother plant[42, 27, 28].

The basis of Photoperiodism

Since the discovery of photoperiodism various empirical facts relating to the basic nature of photoperiodism have been found. They are mentioned below :—

(*i*) *Photoperiodic classes.* Plants in general can be grouped into three classes according to their photoperiodic requirements for flower initiation: Short-day plants, long-day plants, and indeterminate plants[19].

Short-day plant generally require light periods shorter than a critical in 24 hour cycles to induce flowering. The distinctive feature of short-day plant is that a long dark period is essential for flower initiation. The requirement of long dark period is clearly shown by studies using the cycles of less than 24 hours. Such studies with short-day cocklebur have shown that as little as one-half hour of strong light may suffice for inducing flowering if followed by a long dark period of nine hours or more[31]. Different species will of course have different specific requirement of day and night length. If long nights are given but are interrupted by light even briefly the induction effect of the cycles is entirely lost[33].

Long-day plants require light longer than a critical period to induce flowering. The distinctive feature of long-day plants is that long night periods entirely prevent flower initiation. If long nights are given but interrupted by light, even briefly, the inhibitive effect of the night is lost and the plants can initiate flowers. The extreme long-day plants will flower in continuous light and require apparently no period of darkness.

Indeterminate plants are those in which flowering is independent of photoperiodism. Initiation of flowers in these species is not apparently determined by the day-length or the night-length.

(*ii*) *Photoperiodic induction.* It has been observed in a variety of plants that an initial treatment to a light period conducive to sexual reproduction will result in flower and fruit development, though often to various extents, irrespective of the length of day to which the plants are subjected afterwards.

(*iii*) *The nature of the stimulus and the response.*

(*a*) The perception of photoperiodism occurs primarily in the leaves[11]. During expansion leaves are quite insensitive, but as soon as half the maximum size is reached, they show maximum sensitivity to photoperiods. As the leaves age beyond this stage, a gradual decline in relative sensitivity sets in[38].

(*b*) The response is obviously initiated in the bud and consequently the flowering stimulus must move from its place of origin in the leaves to its place of expression in the buds. This stimulus has been found to move primarily in the phloem[11]. Other living cells are capable of transmitting the stimulus, but dead cells killed or naturally dead as in the case of xylem cells cannot transmit it.

(*c*) The response itself is both qualitative and quantitative. As the flowering stimulus reaches the growing points of the plants a qualitative change over from production of vegetative primordia to flower primordia takes place. The quantity of flower primordia formed is proportional to the intensity of the stimulus received, as recorded in the linear relationship between the number of inducing photoperiods and the number of flowers formed in soybean[31]. There are however limits to this linear relationship.

(*iv*) *Relation to temperature.* The modifying influence of temperature on photoperiodism has been known practically ever since the discovery of the phenomenon[20]. Each species seems to have its own temperature range for optimal flowering response. There is however no strong temperature preference characteristic of plants in any photoperiodic class although low temperature preferences are more common in long day plants[48].

Translocation of flowering stimulus is influenced by temperature as temperature close to freezing can stop the photoperiod stimulus in moving through the petiole and the stem. Cooling the petiole of an induced leaf can prevent the movement of the stimulus from the leaf to the buds[8]. Cooling the stem of a weakly induced branch can localise the stimulus in the distant part and result in flower formation where normally the stimulus would be too dilute[80].

Temperature requirements or at least optimal temperature ranges during the light period can be entirely different from requirements during the dark period[69, 78].

Some plants with a photoperiodic requirement for flowering can be modified in that requirement, or in some cases the photoperiods can be entirely substituted for, by a temperature change[47, 65, 103].

Temperature itself, independently of photoperiod may be a potent factor in induction and maintenance of sexual reproduction in some plants. The extensive investigations on vegetables[95, 96] and ornamentals[71, 72] would seem to furnish ample testimony that various plants though responsive to photoperiods can be induced to bloom by temperature treatment alone, commonly by "chilling".

In consideration of the accumulated evidence on the relationship of temperature to photoperiodism, both are now being taken into account in experimental work on the influence of length of day on plant development and either the day or night temperature or both are kept under control.

Thermoperiodicity. It has been found[101] that a variety of tomato, a photoperiodically neutral plant, sets fruit abundantly only when the night temperature is between 17 – 18°C and the day temperature 26°C. With lower and higher temperatures at night, fruiting is reduced or absent. Similarly in *Capsicum annuum*[15], optimal growth was obtained with a day temperature of 26°C and the optimal night temperature dropped from 30°C in young plants to 8°C in full grown plants.

This diurnal alternation in temperature requirement would seem to be a sort of simulation of photoperiodicity to thermoperiodicity[68].

SEPARATION INTO PARTIAL PROCESSES

Thus it is clear that light and temperature as factors of the external environment affect internal conditions in the plant leading to floral initiation. The reactions involved are apparently complex and a clear understanding of the mechanism requires the resolution of this complex system into simple components, the partial processes. A large number of hypotheses have been put forward to explain particular findings of particular type of investigations[45, 32, 25] ; the existence of a large number of hypothetical substances was assumed, usually distinguished by their thermo and photostabilities. Such speculations have no doubt helped in the analysis of the responses of the plants towards environment but have contributed little, if at all, to the biochemical reactions involved.

This much is clear, however, that there exist several well defined partial processes leading to the formation of the so-called floral stimulus. Gregory and Purvis[75] have assumed the existence of at least six substances to explain the photoperiodic behaviour of Petkus winter rye which requires a low temperature treatment followed by long days. These are chiefly based on the thermo- and photostabilities of the compounds involved, their relative rates of synthesis at different temperatures and their stability towards devernalization conditions. Melchers and Lang[62] formulated three partial processes for the flowering of the biennial *Hyoscyamus niger* having different temperature co-efficients. For the photoperiodic response it has been claimed[45] that there are at least three component processes. These are (*i*) a high intensity light process (*ii*) a dark process (*iii*) a low intensity light process antagonistic to the dark process.

The high intensity light process requires a minimum amount of energy of the order of $6 \cdot 6 \times 10^4$ "foot candle-minutes" for short day plants. There is evidence that it may be identical with photosynthesis as light of at least an intensity high enough for photosynthesis is required for this process ; CO_2 is required and the process can be substituted for by various sugars and acids of the Krebs cycle[54]. This high intensity light process presumably supplies the substrates in the following dark reactions which require a minimum time period for the synthesis and accumulation of the so-called flower forming substances, if any. The reactions going on in the dark may be inhibited by the low energy light process which requires only 1/1000th the energy for the high energy light process, does not require any CO_2 in all probability, is not supplanted by sucrose, does not apparently need any chlorophyll and probably has an action spectrum different from that for the high energy process[54].

This scheme applies to a large number of short and long day plants but not all the photoperiod sensitive plants. A notable exception is the succulent *Kalanchoe blossfeldiana* which flowers with only 1 sec. light per day for 65 cycles, the total light energy utilised being only 100-170 foot candle minutes which is far less than the minimum for significant photosynthesis. In *Kalanchoe* thus the high intensity light process is very closely related to the low energy light process which inhibits flowering in short-day plants. It should however be borne in mind, that *Kalanchoe* is a succulent plant with a special type of organic acid metabolism fixing enormous amounts of CO_2 in the dark period ; this CO_2 is given off again when the plants are returned to light[30]. Such plants which have a large supply of storage materials in seeds and tubers e.g. pea, potato, corn, cucumber, flower under total darkness[48] ; there the light energy requiring processes are completely eliminated. It will be shown later that while CO_2 is required for photoperiodic response of short-day plants and vernalisation of Alaska pea, it is not required for long-day plants. Sucrose is required for vernalisation of winter rye but nothing is required for vernalisation of mustard. Metabolic pools of different compounds are probably supplied by different metabolic pathways and the ultimate compound in the photoperiodic reaction can thus be synthesised by alternative pathways.

By an analysis of the different results it has been possible to visualise several daylength and temperature dependent individual processes participating in floral initiation. The processes control the formation of transmissible stimuli. The stimulus appearing as the outcome of the daylength dependent complex of processes in long-day plants is identical with that in short-day plants. The stimulus controls floral initiation in a direct manner, but it is not possible yet to integrate the processes which control the production of this stimulus into one comprehensive story. The stimulus appearing as the outcome of low-temperature dependent complex of processes is different from and has evidently to be present before the former stimulus can be produced, but we do not know the exact relation of the two stimuli. Most likely the stimuli are specific chemical compounds, but their exact nature is quite unknown.

It should however be borne in mind that, whereas the general features of photoperiodism and vernalization are well established and have been found to be identical in numerous plants, the detailed work to understand the nature of the inner happenings and partial processes has been done in many cases with only one or two representatives of each type ; its basis is thus very restricted.

ENDOGENOUS RHYTHM

Bünning's theory of endogenous rhythm is based on the assumption that there exists in organisms rhythmic processes, the rates or periods of which are determined, not by the rhythm of external changes, but by the specific structure of the organism, and which constitute internal conditions dependent directly on the specific structure. There are clear evidences that endogenously controlled rhythmic processes do exist in plants. Diurnal leaf movements are a convenient indicator of these processes. Diurnal rhythms are also known, however, for CO_2 assimilation, respiration, stomatal opening and for the activity of some enzyme reactions in vivo.

According to Bünning's theory of photoperiodism the effect of light on such processes as flowering depend on what phase it is illuminated.[10] That phase of the internal rhythm in which light promotes flowering Bünning calls the "photophile phase", the phase in which light either has no promoting effect or is even inhibitory he calls the "scotophile phase".

The difference between the modes of reaction of the various grades of short-day and long-day plants depends on phase differences in their internal rhythms. We know that the rhythm is set in motion by an external stimulus, which can be a light stimulus. If a plant is so constituted, that only some hours after the light stimulus the photophile phase of its internal rhythm begin, under long-day conditions sufficient light will fall during the photophile phase to bring about developmental changes, leading to flowering. The plant would be a typical long-day plant. Light in its scotophile phase neither inhibits nor promotes flowering. As the photophile activity of the light rises to a maximum and then falls so does its sensitivity to light. This easily explains the experiment of Claes on the long-day plant *Hyoscyamus niger* in which the effect of light in the middle of the dark period following a short day is greater than at the beginning or end of the dark period.

In a short-day plant, on the other hand, the photophile phase of the internal rhythm is set in motion immediately by a light stimulus, so that under long-day conditions, the light is still shining on the plant when it has begun its scotophile activity. Light during the scotophile phase has a direct inhibiting effect on flowering.

Several experiments may be cited to support Bünning's hypothesis. Mention may be made of an experiment with two species of jute in which the effect of shortening of the daily light period in the 8 hours and 10 hours treatments in the morning commencing at sunrise and in the evening ending at sunset was studied.[91] In both the species the flowering took place much earlier in the plants which were darkened in the evening than those which were darkened in the morning in both 8 hours and 10 hours treatments. The difference was much more well marked in *Corchorus olitorius,* where the differences in flowering time were 30 days in 8 hours treatment and 23 days in 10 hours treatment. The vegetative growth of this species was also very adversely affected. The leaves of plants which were darkened in the morning were not properly developed, did not develop the normal green colour and a large number of them were shed.

Melchers[60] shows that many of the complex phenomena on the photoperiodic control of flowering can be explained by Bünning's theory. The nature of the biochemical processes which characterise the phases of the internal rhythm of the plant is still under discussion. According to Bünning, processes of synthesis or assimilation predominate during the photophile phase, whereas hydrolytic or dissimilatory processes predominate during the scotophile phase. Galston and Dalberg[18] support Bünning's theory vigorously as they have been able to observe changes in the activity of indoleacetic acid-oxidase which has been shown to be an adaptive enzyme in relation to environment. Exactly how the photoperiodic stimulus is developed or is prevented from developing, by the interaction of such processes we do not know.

There are however a large number of reports which are contradictory to the existence of any such rhythms responsive to photoperiods. It is also clear that many of the findings on the photoperiodic initiation of flowering can be readily explained without the assumption of an endogenous rhythm and the evidence in favour of endogenous daily fluctuation of activity cannot be considered convincing. There are also two strong objections, namely, the course of endogenous periodicity has hardly been studied with a clear cut daylength dependence of flower formation and that the endogenous periodicity occurs also in day-neutral plants and therefore cannot be the direct basis of photoperiodic responses.

Until now we have been discussing the various ways of interpretations of plant responses towards photoperiods. These are largely based on assumptions which may not be justified and does not explain vernalization and photoperiodism on a molecular basis. We would now be confining our attention to a more direct consideration of the issues.

EXPERIMENTAL EVIDENCE OF THE HORMONE CONCEPT

This much is definitely known that in both long and short-day plants it is in the leaves that the reaction to day length takes place. This was first shown for spinach (long day plant) by Knott[41] and for Chrysanthemum (short-day plant) by Cajlahjan[12] and Moskov.[63] It has since been found to be of general occurrence. Hamner and Bonner[33] showed that also in *Xanthium* the fully expanded leaf is the seat of activity ; young expanding leaves are inactive and defoliated stems likewise. The initial reactions do not take place in the terminal meristems. Clearly, then, the products of the reactions must pass from the leaves to the growing points.

The stimulus is also transferable through a graft union even though their partners vary in their photoperiodic behaviour.[63, 41, 14, 32, 62] Sen Gupta[87] however failed to find any transmission of the flowering stimulus from the donor to the receptor plants in jute, except that in one or two cases grafting delayed flowering in the induced donor plants and it was the post grafting light treatment which had the greatest influence on flowering. Attempts did not succeed in transmitting the flower-inducing effect from one specimen to another by grafting in *Kalanchoe blossfeldiana* (34 ; cf. 60). It has been observed that *Orobanche*, parastitic on red clover, flowers only when the host is in flower, indicating a transmission of the stimulus from the host to the parasite.[37]

Hamner and Bonner[33] claimed that in *Xanthium* junction of tissues is not essential and that the transfer of the stimulus can take place across a "diffusion contact" of the exposed surface separated by lens paper. Withrow and Withrow[104] failed to secure transfer without union of tissues. That living cells are involved in the translocation of the stimulus has been confirmed by the recent works of Galston[16] with soybean and of Melchers and Lang[62] with annual and biennial *Hyoscyamus niger*. Melchers and

Lang attempted to prevent tissue union with agar sheets, Japanese lens paper, cell and membrane filters of different fineness and porosity, but floral initiation occurred only when the graft partners had united.

Grafting experiments have showed that the stimulus is transmissible among short-day, day-neutral, annuals, biennials and even plants belonging to different varieties, species or genera. Plants kept in appropriate day lengths can be made to initiate flowers by grafting ; thus short day plants can flower in long days by grafting on either portions of plants already given the necessary photoinduction, or portions of long day plants.[12, 44, 64, 36] Long day plants can also be forced to flower by grafting on short day plants.[47]

In *Hyoscyamus niger* the biennial variety flowers in the first year, without vernalization, if leaves or shoots of the annual variety already photoinduced are grafted close to the growing points, or of the vernalized biennial variety. The flowering hormone was shown to be non-specific, as other annual plants, *Hyoscyamus albus, Petunia hybrida, Nicotiana tabacum, N. sylvestis,* serve equally well.[57, 58] The evidence thus suggests that the flower hormone is identical in long and short day plants.

Melchers[59] and Melchers and Lang[61] have also investigated the question of the identity of the hormone in biennial plants to determine whether the failure to flower of the biennials in the first year and that of annual plants in inappropriate day lengths arise from similar causes. The problem was approached by grafting the annual short day *Nicotiana tabacum* var. Maryland Mammoth on biennial *Hyoscyamus* in short and long day conditions. It was found that flower initiation occurred in the biennial stock irrespective of whether leaves of the scion were kept in long or short days. Thus leaves of the tobacco kept in long days and therefore not capable of initiating flower on the parent plant in long day did in fact induce flowers on the long day *Hyoscyamus* stock. Melchers[59] concluded from this experiment that the hormones were not identical. The existence of two separate hormones were postulated (1) "vernalin" produced in the biennial only by low temperature (vernalization) and in annual plants without low temperature treatment, and (2) "florigen" produced by the photoperiodic reaction.

FLOWER FORMING SUBSTANCE

The nature of the flower-forming substance will be of great interest. Bonner and Bonner[5] claim to have obtained the floral initiation of 58 out of 68 *Xanthium canadense* plants by an application of the aqueous extract of the apical parts of a palm, *Washingtonia robusta* in flowering condition. Further experiments with the extracts of the growing points of other individuals of *W-robusta, W. filifera* and *Phœnix camerensis* failed to cause floral induction. Behrens[1] brought *Sempervivum* plants in juvenile stage to flower by an "administration of flowering hormones taken from flowering specimens". The florigenically active extract obtained by Bonner and Bonner did not lose its activity even after boiling though the effectiveness was lowered. An oily yellow extract obtained from an unsaponifiable fraction of blooming *Fragaria vesca* applied to leaf blades of vegetative plants induced rapid flowering in Sironvals[93] experiments. According to Loehwing[55] extracts of *Zea mays* are florigenically active. Similar observations were also recorded by Obsil[68] on soybean. Roberts[79] reports about having extracted a flower-inducing substance but the effect is so slight that a conclusive confirmation is urgently required. On the other hand, careful experiments to extract any florigenic substance in *Hyoscyamus* have failed.[61]

Bonner[4] has proposed that the flowering hormone may be protein in nature. He has pointed out that many of its characteristics parallel those of a virus such as curly-top virus in sugar-beet, particularly with regard to translocation, insolubility, and perhaps continued formation. Proteins such as virus mentioned must be swept along by active translocation, they show no polarity of movement, and they are not obtainable with solvent extraction. Proteins such as nucleo-proteins are capable of continued formation in plants once an initial amount has been produced. As evidence suggesting that the flowering stimulus may be able to form even after photoperiodic induction has ceased, Bonner cites his graft experiments in which leaf grafts carried the flowering stimulus to five plants in succession without renewal of the photoperiodic stimulus.

Mention has already been made of the postulated cold-induced floral stimulus 'vernalin' and the day-length controlled stimulus 'florigen' and the different hypothesis regarding the precursors, partial processes and intermediate products. In addition Harder[34] has suggested from his experiment on the photoperiodic behaviour of *Kalanchoe blossfeldiana* that at least four groups of chemical processes are at work : (1) flower-promoting (flowering hormone), (2) flower inhibiting, (3) inducing short-day habit (Metaplasin), (4) inducing long-day habit.

In the experiments on the effect of plant extracts on the induction of flowering referred to before, the extracted plants were usually brought into the flowering condition by photoperiodic treatment. More recently an experiment was set up with rye, to determine if extracts of vernalized grain could confer the vernalized condition on plants which has not received this treatment[76]. Embryos were removed from rye grain which had been vernalized for ten weeks and extracted. At first extraction was done with water, chloroform, ethyl alcohol or ether. In later experiments only chloroform was used as solvent as it was found most suitable. The extracts after removal of the solvents, were added to a sucrose agar medium. Unvernalized embryos were excised and grown for six days on this medium, at a concentration which presented to each test embryo the extract of ten vernalized embryos. A control series was germinated on medium without extract and the seedlings were planted out in sand. It was found that the series treated with chloroform extract showed significant difference. Lower concentrations were without effect. The acceleration of vernalization is small and not commensurate with the amount of vernalized material put into each culture. The effect on the unvernalized embryos is, however, equivalent to that of nearly three weeks of vernalization. The authors suggest that this may be due to the limitations of the extraction technique, or it may be that the active substance is not identical with that produced in complete vernalization.

The stimuli are most likely specific chemical compounds, but their exact nature is quite unknown. The theory that flowering requires the presence of some specific flower-forming substance is rejected by some writers on the grounds that the application to uninduced plants of extracts of induced plants has not led to flowering or at least given conclusive results. This argument is not, however, valid, since the active materials, which are known to move about in the plant and to pass a graft union, may well be inactive in plant extracts. Possible causes of failure are manyfold, the solvent may fail to extract the substance, or may inactivate it ; it may not be absorbed by the test plant in sufficient quantity to produce a determinable effect, or it may only be active in association with living protoplasm.

AUXINS AND FLOWERING

But the absence of any reliable report regarding the successful isolation of the flower-forming stimulus is undoubtedly the strongest argument against its existence. This has led to attempts to explain the flowering behaviours of plants in terms of known biologically active compounds in which the assumption of a flowering hormone is not a prerequisite.

Thus, it may be possible to explain the responses to environmental changes as bringing about fluctuations in the auxin levels of the plant[77, 83, 99], certain levels favouring the development of certain organs viz. stem, buds, roots and flowers[53]. Application of low concentrations of auxins have been shown to inhibit flowering in short-day plants[6, 35, 53] and to promote the flowering of some long day plants i.e. Wintex barley. Pineapple is however the only plant which can be brought into flowers at any stage of development by application of auxins[97]. The extensive literature on the effect of growth regulators on flowering has been recently reviewed[83, 67].

If low auxin levels in the plant is the determining factor for flowering of short day plants, application of compounds which have auxin antagonistic properties in the conventional growth tests, should promote floral initiation. Thus 30 ppm 2,3,5-triiodobenzoic acid induce flower-like buds (under long day conditions) on cuttings of *Xanthium canadense,* and this could be completely inhibited by 10 ppm Naphthalene acetic acid (NAA). The initiation can however be completely nullified by applying an equal concentration of 2,4-dichloranisole which possess some anti-auxin properties.[6]

The auxin level in the plant can also be lowered by increased activities of the auxin-destroying enzymes, particularly indoleacetic acid (IAA) oxidase which has been isolated from a large numbers of plant tissues. Except the work of Galston and Dalberg[18] discussed above there is very little work on the relationship of IAA-oxidase and flowering. Recently pineapple leaf and meristem tissue has been shown to contain large amounts of IAA-oxidase.[24]

Apart from inhibiting enzymes there may also be present in the plant, inhibitors of known or unknown chemical nature, but very little is known regarding such naturally occurring inhibitors. Very recently however an inhibitor has been crystallised from *Xanthium* leaves which is an unsaturated ketolactone with the composition $C_{17}H_{22}O_5$.[3] The concentration of this substance has been found to be maximum in the most sensitive leaves and decreases as the plants are photo-induced. Decrease in the concentration of the inhibitor does not explain how the native auxin level can be lowered. Germination of lettuce seed which has an identical action spectrum as that for photoperiodism was also unaffected by this compound.[56] No significant role can therefore be attributed to this compound as such—so far as photoperiodic response is concerned.

Nothing is also known regarding the influence of light in the effective regions of the spectrum on the auxin levels in the plant, although destruction of auxin by blue light has been demonstrated as an explanation for phototropic curvature in Avena coleoptile, the photoreceptive pigment being a flavoprotein[17]. X-Rays are known to decrease auxin levels[94] and promote flowering[53]. Ionizing radiations lower the free acid auxin and indoleacetaldehyde levels in the plants the extent of inactivation increasing with age[22]. Very recently they have shown that the enzyme system involved in the bio-synthesis of IAA from tryptophan via indoleacetaldehyde is inhibited by low irradiation doses. The radiosensitive locus was found to be the terminal aldelyde oxidation which gives rise to indoleacetic acid[23].

If auxin levels in the plants are concerned in flowering, application of auxins may be substituted for the low intensity light process which nullifies the effects of dark periods. Salisbury and Bonner[81] found application of auxins to be most sensitive when applied 2-3 hours after the beginning of the dark period, the effect decreasing slowly with later applications. Inhibition by light is however greatest when applied in 7-9th hours of the dark period. When both are applied simultaneously the inhibition is greater. According to Lang and Liverman[46] light only increases the sensitivity of plants to applied auxin.

That auxins may be concerned with the vernalization process also is clear from the series of investigations by Leopold and Guernsey[49, 51]. $10^8 - 10^9$ M of NAA were found to be enough for inhibition of flowering in Alaska pea at 18-20°C. The inhibitory effect of sucrose, malic acid or arginine could be neutralised by applied auxins. Alaska peas could also be vernalized by treatment with naphthalene acetic acid, B-naphthoxyacetic acid, triiodobenzoic acid, thiamine etc. followed by low temperature. This promotive effect was reduced by high intensities of light. From their observations involving a large number of plants they concluded that the physiological mechanism which controls flower initiation by photoperiodism, vernalization or other means has probably close biochemical similarities.

Though the weight of the evidence in support of the contention that growth regulators are concerned with flowering is heavy, there are also numerous instances which give indications to the contrary. Thus indoleacetic acid and 2,3,5-triiodobenzoic acid which has marked effect on flowering in so many plants has no effect on the flowering of such short-day plants as jute or sorghum and the day-neutral *Brassica juncea*[90]. There is also no reliable report in the literature on a correlation between auxin levels in the plant and photoperiodic or vernalization treatment. This is largely due to lack of suitable extraction methods. A recent report that Indole-pyruvic acid in soybean leaves increases under photoinductive daylengths is of great interest in this connection[98].

Most workers however do not attribute any direct role to indoleacetic acid or any other native auxin in flowering. It is probably linked up with several metabolic pathways and changes observed by application of auxins are thus secondary effects and not the primary cause. Sen[83] has drawn pointed attention to the role of inhibitors which may have a more important part to play than is generally realised.

MODERN CONCEPTS

Nearly a century of research, thus, since the formulation of the principles of the physiology of flowering by Sachs, has produced very little concrete information on which the biochemical basis of flowering can be laid. A large number of biochemical processes in the plant *e.g.*, carbohydrate metabolism, nitrogen metabolism, water relations[80] is known to be affected by photoperiodic treatment[83] but the findings are inconclusive. The only positive contributions in the field of photoperiodism are investigations on the photoreceptor pigment by the workers at Beltsville in U.S.A. and the very recent researches on the role of CO_2 fixation in light and darkness. These will be discussed now.

Borthwick, Parker and Hendricks[9] studied the wavelength dependence of the photoperiodic response by subjecting the plants to different wave-lengths of light applied in the middle of a long dark period. The effectiveness was plotted against the corresponding wavelength and the action spectrum curve was obtained. It was found that the curve for initiation of short-day plants was identical with that for the promotion of flowering of longday plants. This curve has a peak at 6200A-6400Ao. Thus the red region of the spectrum is the most effective but the effect of the red light can be nullified by infra red light following immediately. Later it was found that action spectra for germination of lettuce seed, elongation of barley stem, inhibition of elongation of Avena mesocotyls, leaf growth and shortening of internodes of eliolated pea seedlings had the same action spectra[70, 7]. Thus apparently unrelated growth phenomena are controlled by the same mechanism involving a photoreceptor pigment which is susceptible to red and infra red radiation. According to their latest observations the pigment which has an absorption maximum at 6600Ao is converted to its isomer absorbing maximum at 7350Ao. Of known pigments phycocyanin alone has an absorption spectrum corresponding to this pigment but phycocyanin has yet to be isolated from higher plants. Protein with non-cyclised tetrapyrrole chromophoric groups with completely conjugate double bonds may also satisfy the requirements. The pigment has not yet been isolated or identified. Very recently Blaauw-Jansen[2] has isolated a chlorophyllide from *Chlorella* which has been suspected to have the same absorption characteristics as the pigment responsible for photoperiodism. The evidence is however too meagre to justify its identity with the photoreceptor pigment and further information must be furnished before any importance may be attached to its role in growth and development phenomena.

Physiological significance of such a pigment is great but the substances formed through its agency or the biochemical changes such a photochemical reaction may initiate are unknown. Leopold and Guernsey[52] studied the respiration rates of tissues exhibiting such growth and development responses controlled by the pigment as described above. They observed that red light has the same effect on respiration rates as on the response exhibited and infra red has the opposite effect. Later it was found in Leopold's laboratory* that CO_2 is required during the dark period of photoperiodic induction for short-day plants, as also germination of lettuce seeds. More recently Yamaki[105] has demonstrated the necessity of CO_2 for elongation of *Avena* coleoptiles. Thus the various responses are connected, indirectly at least, with different metabolic pathways but the missing link has not yet been found.

Following the discovery that dark fixation of CO_2 is essential for flowering of shortday plants Sen and Leopold[84] allowed 2 short day plants—Biloxi soybean and Cocklebur and a long day plant Wintex barley to metabolise $C^{14}O_2$ during inductive and non-inductive dark periods. It was found that $C^{14}O_2$ is fixed in the dark and metabolised into a large number of compounds primarily in the phosphorylated compounds. In shortday plants there is considerable decarboxylation in the second half of the 16 hours dark period, and a large number of compounds are metabolised away. For the long day plant opposite is the case, compounds are formed continuously and new compounds appear in the second half of the dark period. Later Sen and Leopold[85] found that the rate of photosynthesis is markedly diminished in induced plants just coming into light, but the rate of steady-state photosynthesis in the 7 days-induced plants was 7 times that of the non-induced in both short and long day plants. New compounds are formed photosynthetically and non-photosynthetically by light. Most of the C^{14} is found in sucrose, malic acid, glycine, serine, alanine, threonine etc. These are the products formed in the high intensity light process and are found to be metabolised away as the dark period gets longer probably through the metabolic reactions leading to the synthesis of the suggested flower-forming substances. If CO_2 is essential for flowering and if the photoperiodic stimulus is perceived in the leaves and translocated to the growing points where floral primordia are formed, then in the buds of the induced plants allowed to metabolise $C^{14}O_2$ some C^{14} labelled compounds should be present which would not be detected in the vegetative buds at least in the same concentrations. This was found to be so. The compounds had moderate R values in phenol water and butanolacetic acid water on two dimensional paper chromatograms ; but they were not identified or their florigenic properties tested.

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* Personal communication from S. P. Sen.

It has not yet been possible to formulate the biogenetic pathways of the compounds involved but respiration, dark fixation of CO_2 and photosynthetic rates measurements following dark periods of different lengths indicate that all the rates become stationary for some time over the critical dark period in *Xanthium*. Sen and Leopold[85] suggested as one of the possible explanations the limiting concentration of pyruvic acid and the activity of pyruvic oxidase, the prosthetic group of which, 6,8-thioctic acid, has recently been claimed to be the key point controlling dark and photosynthetic fixation of CO_2[13].

This is the state of the field at the moment. The recent developments in the investigations on the pigment and the CO_2 fixation studies have been two great steps forward and it seems for the first time that the solution is in sight. These observations have initiated the biochemical approach to the problem but the goal is still far off. Recent improvements in analytical methods coupled with the advancement that has been made in the last five years should provide enough incentive to all workers in the field to solve this most fascinating and intriguing problem in plant physiology. We should not rest until the active compound is isolated, identified and when applied to vegetative plants brings them into flowers.

VERNALIZATION AND PHOTOPERIODISM IN INDIAN AGRICULTURE

This will be of great significance to agriculture. All the researches in vernalization and photoperiodism have contributed very little to crop production, except in U.S.S.R. The apparent promise of increased crop production was taken rather seriously by Indian workers and the large volume of work on our economic plants has been of more academic interest than agricultural. The plants studied include rice, wheat, mustard, cotton[92], pulses, jute, sesamum, sunn hemp, subdariffa, soybean, jowar, tobacco[88, 89] etc., but the available information is of little use ; the earliness with vernalization if any is small and the method of application of photoperiods on large agricultural plots is impracticable under the present conditions. Photoperiods can however be used for certain horticultural plants and for facilitation of breeding experiments.

Auxins may be applied to control the flowering of certain plants. At the pineapple plantations in Puerto Rico such auxins as naphthalene acetic acid are sprayed regularly and is now as common an agricultural practice as manuring. This is changing the face of the pineapple industry considerably. Pineapple is however one of very few plants the flowering of which is promoted by application of auxins. No matter whether the flower forming substance is isolated or not, efforts should be intensified to search for synthetic compounds capable of bringing most if not all plants into flowers. Success in this will no doubt make the prospect of increased production of crops in India and the world, brighter.

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SECTION OF ZOOLOGY AND ENTOMOLOGY

PURNENDU SEN, M.Sc., Ph.D. (Lond.), D.I.C.

PRESIDENTIAL ADDRESS

ECOLOGY OF ANOPHELINE MOSQUITOES

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I am deeply conscious about the honour you conferred in electing me to preside over this session of your section and for giving me the opportunity of addressing you. While thanking you all for the privilege bestowed I must confess that in considering what might be a suitable subject for this occasion I felt a little bewildered. When I recalled some of the past addresses from this chair I realised that perhaps the least vexatious would be to restrict my observations to a subject on which I have had occasions to make some humble contribution. I refer to the subject of anopheline ecology which is not only highly fascinating but offers scope to helping mankind in their attempts to solve one of their worst miseries—the malaria—transmitted by *Anopheles.*

I. INTRODUCTION

Since the days of Ross and Grassi the anophelines have received close attention of research workers all over the tropics, but never in history was the pace of progress in the study of this group of insects developed such importance as during the last one and a half decade. A number of anophelines acts as vectors of malaria, one of the worst diseases of the tropical countries. Efforts were mostly directed in the past to study the systematics and biology of the insects as they came up, but any serious attempt to study their complicated life processes or ecology which is in fact linked up with intensive field observations in relation to the natural environments is comparatively a newer offshoot. We have a few good examples of ecological studies recently carried out in India that of *Anopheles minimus*[59, 60, 61] in Assam and *Anopheles culicifacies* in South India.[31, 33, 34] Such studies points to the beginning of a changed outlook of workers in the line and we feel that this has become a more urgent necessity since the introduction of synthetic insecticides like DDT in mosquito control operations which entail that more detailed knowledge of the habits and behaviour of the mosquitoes must be amassed if success has to be achieved. So vast and complicated is the scope of the subject that I feel it necessary to confine myself to certain aspects only of the problem which received some attention in my own State and to take a stock of the knowledge that has accumulated in this direction without attempting a complete linkage of the progress made elsewhere primarily on consideration of space.

II. TOPOGRAPHICAL INFLUENCE ON ANOPHELES

The topographical and climatic features of Bengal are so varied that it is no wonder that its fauna should be so variable in different parts. The whole region from the Himalayas to the Bay of Bengal has been divided, more peremptorily than on geologic basis, into 5 or 6 definite zones[43] and the distribution of anophelines shows that each zone has its distinctive population (Table I).

TABLE I.—ZONAL DISTRIBUTION OF ANOPHELINES OF BENGAL

1. Montane	Darjeeling Hills	*A. gigas, A. lindesayi, A. willmori, A. aitkeni, A. leucosphyrus.*
2. Submontane	Foothills & Terai including part of Jalpaiguri and Cooch-Behar	*A. minimus, A. maculatus, A. aitkeni, A. annandelai, A. insulaeflorum, A. karwari, A. kochi, A. jamesi, A. leucosphyrus, A. majidi, A. splendidus, A. theobaldi, A. jeyporiensis, A. philippinensis.*
3. Lateritic	Bankura, Birbhum, Murshidabad bordering Bihar	*A. culicifacies, A. philippinensis, A. fluviatilis, A. splendidus, A. tessellatus, A. theobaldi, A. stephensi, A. pallidus, A. aconitus.*
4. Palaeoalluvial	Northern districts, Murshidabad, Nadia, Burdwan	*A. philippinensis, A. pallidus, A. varuna, A. culicifacies, A. ramsayi, A. tessellatus, A. aconitus, A. stephensi, A. theobaldi.*
5. Neoalluvial	Howrah, Hooghly, Midnapore, 24-Pargs.	*A varuna, A. aconitus, A. ramsayi, A. stephensi, A. philippinensis, A. pallidus, A. sundaicus.*
6. Estuarine	Saline tracts nearing sea in 24-Pargs., Howrah and Midnapore (*Sunderbans*)	*A. sundaicus.*

The widely distributed species *A. hyrcanus nigerrimus, A. barbirostris, A. vagus, A. subpictus* and *A. annularis* which are of common occurrence have not been included in the above list. Some mixing up of the species between two contiguous zones does prevail owing largely to interference in the original habitat of the species concerned and to setting up of environments suitable to the species in unexpected areas. Thus the foothill species *minimus*, one of our major vectors up in the north, and *maculatus* are seen in the montane zone also up to a certain height but not usually above 4000 ft.[58] The high altitude species *aitkeni* has likewise been recorded from the submontane zone. *A. philippinensis*, the primary vector of the lateritic and alluvial zones may also digress into the submontane zone. Another good example of this overlapping is afforded by the species *sundaicus*, our chief menace in the estuarine zone. This species although essentially a sea-front breeder has lately spread further inland along the industrial belt on both sides of the river Hooghly around Calcutta (Fig. 1).

The urge of colonisation is inborn with all animals. The instance of *sundaicus* invasion just mentioned illustrates this admirably. The species although originally recorded from cleared areas in *Sunderbans* with extensive saline tracts or swamps fed by sea water as in Dutch East Indies and Malaya has recently taken to breeding around Calcutta in waters which can no longer be called saline or even brackish.[41]

Despite this overlapping of territorial zones by certain species of more vigorous type a vague tendency with a number of them to stick to their characteristic physical or biological divisions can still be determined. In analysing such spatial distribution of species within a well-defined geographic region, we find that climatic and vegetation factors have influenced this much more than anything else. Most of the species mentioned under montane zone belong to subgenus *Anopheles* and are shade-loving species as denizens of dense forests. They are best suited to the cooler atmosphere

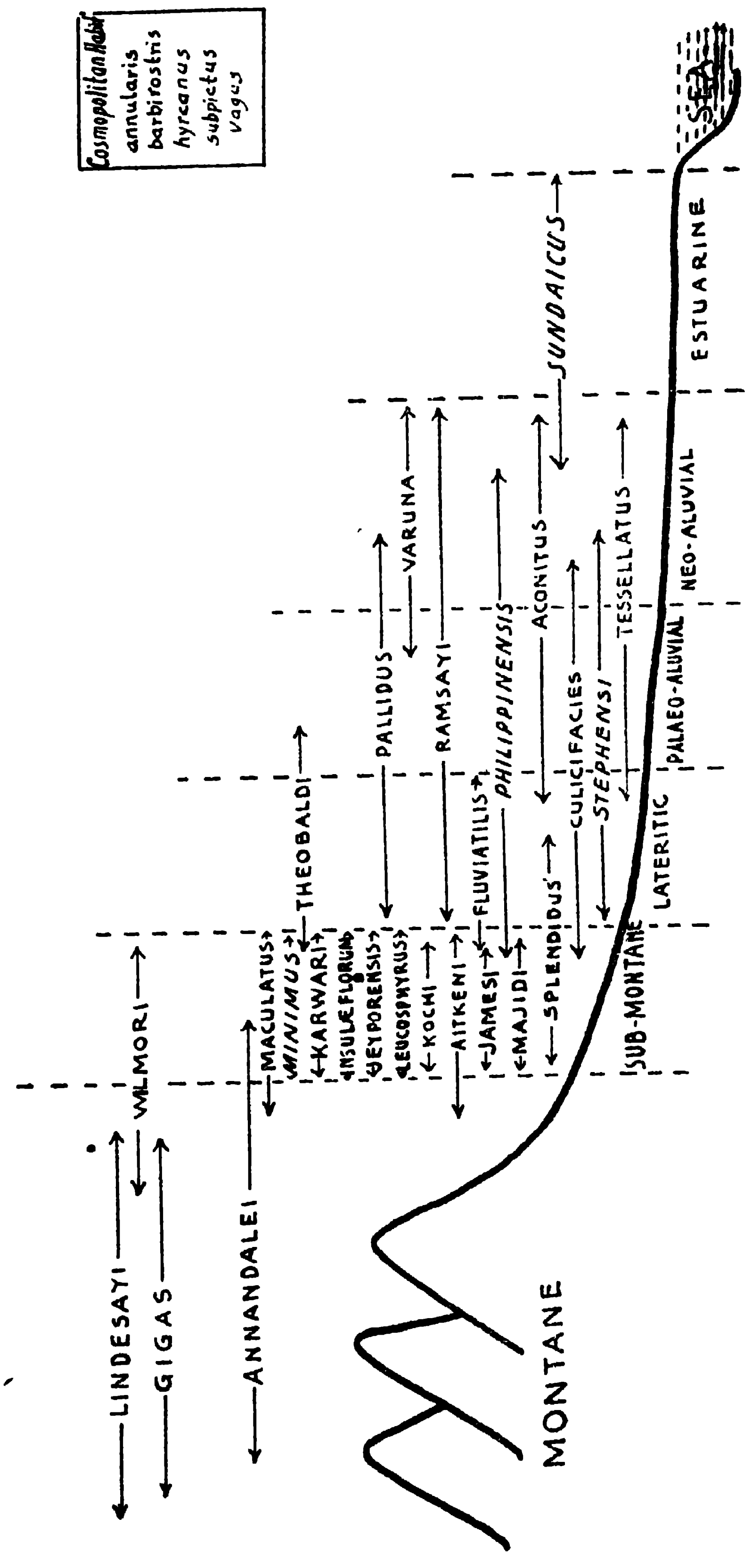

FIG. 1. Diagrammatic representation of the different zones of Bengal with their anophelines.

at high altitude. The subgenus *Myzomiya* is strikingly absent in this zone and the preponderance of alpine oriental species is the rule. But if the forests are cleared and open tracts with slow-running streams are available the species *minimus* makes its appearance and continues to breed there so long as the conditions prevail.

A. stephensi of which both the type and *mysoriensis* forms are prevalent in Calcutta notwithstanding the solitary record of its incrimination with malaria transmission[55] has not given any cause of alarm. The extremely rare manifestation of the species in hand catches from dwellings in Calcutta indicates lack of dynamics of the species,* or that the adults do not normally take to indoor shelters.

The vectors, as we have seen, are distinct for a zone and rarely would two of them occur at any one place and time, but where such events happen the species primarily responsible for malaria transmission excels the other by no less than 30 to 50 times numerically.[26]

III. SEASONAL INFLUENCE ON ANOPHELES

The general environment varies within a given region and the local distribution of a species is controlled by reactions to the environmental differences among the available range of habitats. The seasonal variations in anopheline density give us a method of approach to the ecologic relationship of different mosquito population. The variations studied were based on standardised capture of diurnal mosquitoes from collecting centres and in box traps at night. Mosquitoes per catching area have been used for study of fluctuations in density during the various seasons.

A. subpictus has the maximum prevalence during the dry weather, once from April to June and again during November to December, and drops with the onset of rains ; whereas *vagus* has its peak during the rains from July to September or even October if rains continue. Both *hyrcanus* var. *nigerrimus* and *barbirostris* may prevail during the rains, but there is a peak also during December to February ; they are extremely rare during the period April to June.[12] *A. varuna* is usually most prevalent during August to October when the atmospheric temperature is about 87°F or 88°F and the humidity 75 to 80 per cent. It prevails within a very small climatic range and drops with the onset of cold weather.[35 38] *A. aconitus*, on the other hand, prefers the cold weather showing its maximum prevalence during January to March and disappears with the rise of temperature. *A. annularis* also has its peak almost about the same time but the ascendancy starts from December. May and June appear to be the lean period for the last three species. *A. sundaicus* shows its maximum incidence during September to December, and there may be another short rise in May when there is a little rainfall mellowing the temperature to some extent. The best temperature range for the species appears to be 80°F to 90°F when the relative humidity averages between 65 and 84 per cent. *A. philippinensis* likewise appears essentially an autumnal species with the maximum prevalence during August to December having almost analogous temperature and humidity factors as those of *sundaicus*. In certain badly infested rural areas the species may trail on to March.[47] *A. ramsayi* appears in large numbers during August to November or December when the temperature varies from 80°F to 90°F with the humidity at 65 to 88 per cent. *A. pallidus* is mostly seen in December, and *culicifacies* during March-April and through July if there is a late rain, when the temperature varies from 90°F to 95°F with the humidity at 70 to 75 per cent.[55] *A. minimus* has its maximum incidence during September to November and again in April-May when the winter is over. The mean maximum temperature at the first peak varies from 77°F to 90°F, and this may rise in spring to 85°F to 90°F. The humidity for the corresponding period differs very little, 84 to 90 per cent in the autumn and 75 to 85 per cent during April-May. The maximum density of *stephensi* is noticed in July-August at the temperature of 85°F to 90°F and at 85 to 90 per cent humidity.

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* Calcutta receives anti-mosquito measures : the low incidence of the species may be partly due to these.

The two climatic factors, temperature and humidity although differ among the various species, overlapping of ranges is also not uncommon ; and a digression from one range to another is not always inimical.

One other factor, the rainfall, appears to bear a closer association in determining the seasonal distribution of the different species, no doubt, by affecting the larval life and habitat more directly. Both *sundaicus* and *philippinensis* find a rainfall of 3″ to 7″ during a month more congenial to raise their number.[38] *A. subpictus* also finds a similar range 4″ to 8″ good for it. *A. culicifacies* prefers a range of 5″ to 10″ of rainfall, and *ramsayi,* a range of 7″ to 10″. A rainfall of 7″ to 8″ seems favourable for *varuna* and 10″ or so detrimental to the species. *A. vagus* likes 8″ to 12″ of rainfall, while *stephensi* 10″ to 12″ or more. *A. minimus* requires the heaviest rainfall ; from 16″ to 40″ is the favourable range and at about 10″ the number falls.[57] Consequently the species becomes rare from January to March or April when the rainfall is virtually absent, or at the most not exceeding 3″ or 4″ in any one month even if it rains.

IV. ADULT BEHAVIOUR

EMERGENCE : The time of emergence is of special interest in anopheline ecology ; the ease with which mosquitoes can infest our dwellings depends on this to a great extent. The imago immediately after emergence cannot fly. Its wings have to dry and harden and this takes different time in different species. *A. annularis* takes about 1 to 2 hours to emerge from the pupal case, while *barbirostris* may perform this function in 8 to 30 minutes[16] They are vulnerable to their predators, such as, the water striders and other larger Hemiptera and a few other insects, and surface feeding fish like. *Aplocheilus* at this stage. The maximum emergence of most anophelines occurs during the dark hours of 6 to 9 P.M. when about 50 per cent of the total mosquitoes in a brood emerge. In *culicifacies* and *hyrcanus** maximum emergence has been noticed between 9 P.M. and midnight. This behaviour of night emergence confers a special advantage to the mosquitoes in escaping their day-time predators.

A. stephensi seems to be an exception in this respect in having an emergence time between 3 and 6 P.M. The almost complete failure to make day-time collections of the species in Calcutta by several workers possibly depends not in a small manner on this interesting diurnal emergence when their lodgement into rooms would be highly unprofitable on account of severe competition from spiders and geckoes. This takes us to another problem, the question of preferential resting habit.

SHELTERS : We no doubt know the day-time resting places of some anophelines, but a large number has yet remained a guess work. Certain species, particularly *culicifacies* which is a vector elsewhere seems to have a special attraction for cattle sheds in Bengal like the innocuous

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* In Bengal *hyrcanus* refers to *hyrcanus* var. *nigerrimus.*

barbirostris, hyrcanus, subpictus, and *annularis.* On the other hand, three of our efficient vectors mentioned above, *minimus, philippinensis* and *sundaicus* are essentially a house frequenter: twice as many adults have freely been captured from dwellings as compared to those of cattle sheds.[14] The position on the wall surface that the different species take up while resting is another interesting feature. *A philippinensis,* for instance, rests very close to the floor within 1′ to 1′6″ from the ground level of rooms. The species has also been found resting on sooty pots and other utensils usually seen lying on the floor of kitchens in the rural areas of Bengal.

With regard to *philippinensis* doubts have recently been raised as to the merit of the day-time indoor catches of the species[50] which has been known resting among outdoor vegetations in other countries,[16 66] and we are more inclined to the belief that a large population of this mosquito in recent years has been resting outside after feeding in our areas also. The sparse representation of the species in routine catches even from endemic areas where this has been the established vector lends support to the view.

Besides houses and animal sheds, boundary walls, crevices and hollows in outdoor walls, culverts, tree trunks and shaded banks of streams, reeds and grasses are also utilised as resting places.[30] We have already referred to the extreme paucity of *stephensi* mosquito in rooms. The adults, however, have been known from outdoor shelters, such as, the overhead unfiltered water storage tanks of galvanised iron which gets so heated during the afternoon that life becomes perilous in such a precarious shelter.

When the total annual catches from the deltaic tract where *sundaicus* is the vector are analysed in terms of percentage infestation between this and two other associated species, *annularis* and *hyrcanus,* the *sundaicus* is excelled in density in bed rooms by *annularis* only. But in cattle sheds the *sundaicus* happens to come at the bottom.[39] The *annularis* taking a top position in bed rooms, however, cannot numerically surpass the cattle shed catches. All these are highly suggestive of the dissimilar feeding habits of the species encountered.

FEEDING HABITS.—Males, as is well-known, feed only on vegetable or fruit juice in nature and are non-biters., Most female anophelines, however, feed readily on blood 48 hours after emergence. But not all feed on human blood normally. Uses of traps with animal baits and of precipitin tests have proved that the species concerned in malaria transmission, *minimus, philippinensis,* and *sundaicus* have a high anthropophilic preference. As much as 86 to 94 per cent of *sundaicus* and 89 per cent of *minimus* mosquitoes in wild catches may contain human blood.[63 64] But others, *maculatus, hyrcanus, kochi, subpictus, vagus, annularis* and *splendidus,* essentially feed on cattle blood ; their stomachs do not show human blood in more than 10 per cent instances. In *stephensi* of Calcutta this index was even lower at 3·5 per cent.[28] At the same time *subpictus* showed an index of 25 per cent[27] which is much higher than the expected figure elsewhere : the dearth of cattle in the area must have helped to divert the species more and more towards human shelters, and a rise in the anthropophilic index is the logical outcome. The same has probably happened with *culicifacies* which in areas where it is not a vector may show an index of 27 per cent.[34] But both *culicifacies* and *stephensi* are not very abundant in Bengal and their anthropophilic indices reported are only relative. *A. leucosphyrus* which is one of our hill species may show a high anthropophilic index, as much as 75 per cent.[22] This species should be looked on with concern, particularly as it has been proved a vector[4] in regions of Assam.

That many species are not highly sensitive to their blood feed, and can take over to alternative sources, have very cogently been reported from Indo-China where ***minimus, maculatus, jeyporiensis*** and ***hyrcanus*** show in the absence of cattle a high incidence of human blood (89%) in the stomach, but in their presence the index may be as low as 8 per cent.[63] Even *minimus* which is so perfectly a homophilic species in India would adapt to buffaloes.

The maxillary indices also afford some clue as to the feeding habits of the anophelines, but as a criterion of pathogenecity these are not considered as absolute and not as reliable as the other methods just mentioned. The zoophile species have multidentate maxillae as in *hyrcanus* and *vagus* with the indices at 15·7 and 14·2 respectively.[8] The paucidentate maxillae are seen in anthropophilic species, such as *minimus* and *jeyporiensis* which have low indices of 11·3 and 11·9. *A. aconitus* with an index of 15·5 in India is another example of multidentate zoophilic species.[54] The records cited so far compare admirably with the two types of feeding habits discussed here. But an ecologic variance challenging the validity of the assumption has also been reported from Indo-China where *aconitus* although a zoophile like the Indian strain has however paucidentate maxillae with an index of 11·2.[9] Paucidentate condition should not therefore be always considered as an indication of anthropophilism, neither is multidentate probably a certain pointer to zoophilism.

SEX RATIO.—The sexes on emergence are not always equal.[3] In most species the females usually constitute 60 per cent of a population in bred specimens, or in other words, the sexes are represented in the proportion of 2 males to 3 females.[36] But if only the dry weather emergence is considered the sexes may appear on a 50 : 50 basis. This has been specially found in *sundaicus* during the period February to June. Similar seasonal fluctuations in the sex ratio have also been noticed in *annularis* and *culicifacies*[17] But when the rains set in and in cold weather the females again rise in number giving them an ultimate overall preponderance as stated above. One interesting observation has been that the output of males may be increased if the larvae are fed on a protein diet in the shape of crushed fly or reared in natural breeding waters,[17] evidently rich in zooplankton.

Among wild caught anophelines, on the contrary, the males seldom exceed 10 per cent of a year's catch indoor as in *sundaicus,* usually less : the exceptions being *subpictus* and *vagus* with the figure at 20 per cent.[39]

MATING.—Mating in small cages under laboratory conditions among anophelines has been almost impracticable. We have so far failed to get any satisfactory evidence of the occurrence indoors excepting perhaps in *stephensi* which seems to adapt itself readily to laboratory culture.[32] The nearest homely atmosphere that would satisfy these insects, particularly *culicifacies,* for swarming and mating seems to be an insectary of the size 10′ high and 40′ × 20′.[34] It was not possible to induce mating in *minimus* in a cage measuring 2′ × 2′ × 2′, but *fluviatilis,* a related species, could be made to do so in presence of blue light.[18] The nature and intensity of light therefore appear to play a very important part in this respect more than the space.

Whatever records we have, lead to substantiate the view that nuptial flights are best accomplished outdoor at dusk when darkness has fallen over earth. Swarming takes place more often near the breeding places as seen in *sundaicus, subpictus* and *vagus* over the salt lakes near Calcutta. Nevertheless, the sexual urge is so great with them that they would undertake a long flight even up to 2 miles to perform the function as the reported swarming of ***sundaicus*** and ***subpictus*** off the Chilka lakes in Orissa coast would tend to indicate.[24]

Cross-mating has been recorded between ***subpictus*** and ***vagus,***[37] and the phenomenon is probably more common than is usually believed. The hybrid generation with the ***vagus*** character dominating as a result of crossing between these two species would interbreed with pure ***subpictus*** and to all evidences the resultant progeny would comprise 50 per cent of each type, *vagus* and ***subpictus,*** following the principle of true Mendelian segregation. Successful cross-mating between *A. gambiae* and *A. melas* has also been reported from Africa,[62] and the phenomenon is too well-known in *A. maculipennis* of Europe.

FLIGHT RANGE.—Not much work has been done to determine the flight range of mosquitoes in this country. But from scrappy reports it appears that most species do not fly out far from their site of oviposition if food is available close by, at least that holds good for ***annularis, hyrcanus,*** *barbirostris, varuna, aconitus* and *ramsayi* as observed in our studies. Although *varuna* is unable to fly long distances, its near ally ***minimus*** in other areas can fly with ease a distance of one mile,[7] and so can ***culicifacies*** in South India when in need of food [31] ***A. philippinensis*** and ***pallidus,*** like *fluviatilis* and *maculatus* would not, as a rule, fly out over ¼ to ½ a mile in India, although the last-named species in Malaya has been known to cover a distance of 1¾ miles.[65] The longest distance covered by Bengal mosquitoes in dispersal has been noticed in *sundaicus* which could be recorded in areas nearly 3 miles out from its possible breeding site. My record shows, contrary to popular views, that the males of the species do not lag behind their consorts in this respect. We have however failed to establish whether this distance is completed in one straight flight or in relays. Some of the long distance fliers from outside India are *A. quadrimaculatus* of America covering 1½ miles, *A. funestus* of Africa with a 2-mile range and *A. maculipennis* of Europe, perhaps the toughest species, with its flight record of 4 to 6 miles.

The flight range not only varies with different species but may also change within the same species from place to place, for although in Calcutta *stephensi* seldom travels, in fact the species does not want to stir out from its domestic assignments, this in other parts has been known to fly out 1½ miles.[1] The principle underlying this variation in the flight behaviour seems to depend not on one factor, the search for food, but on a group of complex environmental factors: food, mating and an inner urge for dispersal.

TRANSPORT.—Apart from voluntary flights in search of food or favourable breeding sites, the anophelines have been known to be mechanically transported through shipping, locomotives and country crafts, and this has been one of the most common ways of colonisation of species in distant areas. The instance of ***sundaicus*** invasion in Bengal has already been cited. The species was not known causing havoc anywhere nearer coastlines of India beyond Andamans in 1912.* From this date to its inland recovery at Port Canning and Budge Budge (Bengal) in 1930 must have been an unwritten history of continuous assault by the species to colonise the virgin swamps lying behind ***Sunderbans,*** and the only possible route of travel during that period appears to be the sea, and country crafts on merchandise must have been extensively used in this attempt. A recent study has revealed unfailingly that this was the agency employed in their next hop from Port Canning and the *Sunderbans* to the environs of Calcutta. Nearly 4 per cent of country boats carrying cargo to Calcutta were infested with *sundaicus* which had been picked up *en route* while passing through *Sunderbans,* lower down.[44] These mosquitoes subsequently dislodged themselves at the salt lakes to the east of the city of Calcutta when the boats were being detained for checking up at the toll points adjoining the lakes. Considering the huge river traffic, Calcutta has to face every year this percentage infestation amounted to a number not inconsiderable. The species along with *subpictus, vagus* and *varuna* was found sheltering in such cargoes as straw, jute and paddy (unhusked rice) among others.

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* Earlier records by Gravely from Port Canning in 1910 and by Brahmachari in 1912 from a Calcutta tank are doubtful cases.

The railway traffic from the south converging to Calcutta was responsible in no less a manner in this inland invasion of *sundaicus,* and nearly 15 per cent of the incoming trains were importing the species at one time. This was the *modus operandi* of the species in its attempt before it finally succeeded in settling round the city during 1934 to 1936.[41] Ten more common species including *philippinensis* and *stephensi* were being transported in the same way through the railway traffic, but in insignificant numbers.

V. LARVAL HABITS AND HABITAT

In the montane areas of Darjeeling district the main breeding places are *jhoras* (streamlets), seepages, drains, puddles and borrow-pits. In the submontane zone, *jhoras,* canals, streams, river beds, *jheels* (lakes) and borrowpits are the chief sources. In the upper deltaic zone the breeding sources are the neglected ponds, tanks, dying river beds, irrigation canals, borrow-pits etc. In the estuarine zone, the tidal creeks and ditches, canals, and series of borrow-pits along embankments fed by tidal waters, as also swamps formed by silted up river beds constitute the menace.

HILL STREAMS AND JHORAS.—*A minimus* the most important species in the montane and submontane zones breeds in slow-running streams and *jhoras* (streamlets). *A. lindesayi* and *jamesi* have not been found to breed anywhere except in the *jhoras* and drains. *A. maculatus* likes the same habitat as *minimus.* In *jhoras, maculatus* has been known to constitute 30 per cent of the total collection, while *minimus* 12 per cent.

RIVER BEDS.—In the lateritic moor countries in upper deltaic zone the pools formed in dying or drying river beds provide suitable breeding forum for species like *culcifacies* and *stephensi* when the water is fairly clear. But in many dead rivers with profuse vegetation *philippinensis* is often found along with *aconitus* and a few other common species.

PONDS AND TANKS.—*A philippinensis* mostly breeds in ponds and tanks overgrown with the appropriate vegetation, submerged and floating, in rural areas of the plains of Bengal. *A. hyrcanus, barbirostris, subpictus, vagus, annularis, pallidus, ramsayi,* and *varuna* are also fairly common in tanks and ponds.[45] *A. culicifacies* is seldom recorded from such places. Old disused and neglected ponds are the most favourite breeding places in rural areas.

WELLS.—Open wells in submontane zone often breed *minimus* and *maculatus.* In the deltaic zones these may provide breeding facility to *culicifacies, stephensi* and *varuna.* Other species like *hyrcanus, subpictus* and *annularis* have also been found to breed occasionally, but the breeding is never intensive.[57] The wells when in constant use are not so suitable for breeding purposes.

ARTIFICIAL CONTAINERS AND CISTERNS.—*A. stephensi* in Calcutta invariably breeds in the defective overhead tanks of unfiltered water without any evidence of floatage on surface. Other containers like concrete underground cisterns and receptacles used by masons for soaking bricks and abandoned pans and pots and rainwater puddles may also show the breeding of the species[25] along with the ubiquitous species, *subpictus* and *vagus*.

SALT WATER POOLS.—*A. sundaicus* breeds in pools which are touched by the spring tides and in those formed by percolation of salt water through embankments of tidal channels. It appears to be absent from places where the tide runs in and out freely. The flow of water when obstructed by *bunds* (dikes) and locks creates the most favourable condition for the breeding of the species in the estuarine zone. A salinity over 0·1 per cent and a trace of nitrite to indicate organic pollution seem a desirable set-up for its breeding. Other species associated in such environments are *subpictus, annularis,* and *vagus* if the salinity is not excessive.

The tides penetrating inland into low-lying areas have in course of time lost their flow back as silt deposited on the mouth, and the water thus accumulated has been broken up into innumerable fish ponds and *bheries* or shallow watery areas by short embankments. These constitute the most formidable breeding places of *sundaicus* in Bengal.

IRRIGATION AND NAVIGATION CANALS.—In the submontane zone the irrigation canals provide good facility for the breeding of *minimus* and *maculatus*. In the upper deltaic zone these canals when the flow is insufficient show the breeding of some common species of which *annularis* and *vagus* together constitute nearly 50 per cent of the total collection.[57] In the lateritic country to the west of the State *culicifacies* may breed in such places. The navigation canals in lower deltaic zone frequently furnish breeding facility for *sundaicus* particularly when the lock gates at the mouth of the canals remain closed for sometime impeding the free flow of tidal water. *A. stephensi* has also been recorded at times from such canals along with a few more common species, *subpictus, barbirostris* and *annularis* when the water stagnates.

BORROW-PITS.—In the borrow-pits in montane zone along highways and railroads *maculatus, minimus* and *kochi* would casually breed, although these by no means constitute the normal habitat of the species. *A. subpictus, vagus, hyrcanus, annularis* and *varuna* are usually recorded from these pits in the deltaic zone when vegetations appear in them. In the lower Bengal with tidal influence the borrow-pits, particularly along the railway embankments, have often been the favourite breeding site of *sundaicus*. We have so far no records of *philippinensis* or *stephensi* breeding in such sites. In the plains *vagus* has been known to form 50 per cent of the total catch from borrow-pits, *hyrcanus* following next with 28·8 per cent.

VI. AQUATIC PLANTS AND ANOPHELINE BREEDING

A study of the association of different aquatic plants with the breeding of the various anophelines comprising a dozen species, in the plains of Bengal has revealed that the larvae of *philippinensis* among others were associated with almost all types of plants studied excepting *Lemna* (duckweed) ; but the species was most frequently associated with the alga *Spirogyra* sp. in common with *subpictus* larvae. Larvae of *ramsayi* were almost exclusively associated with *Pistia stratiotes* (water lettuce) ; their association with other plants was almost negligible.[45] This association yielded on an average 3·6 larvae and 0·9 adult of *ramsayi* per observation. *A. hyrcanus* while showed a disliking for *Ceratophyllum* and *Hydrilla* was not averse to *Pistia*. Waters with *Hydrilla verticillata* and next to this with *Ceratophyllum demersum* were most associated with *annularis*. The high incidence of 14·6 larvae and 3·1 adults of *annularis* per observation was noticed from this association. *Utricularia* as supposed is not always detrimental to anopheline breeding and the plant has a close association with *pallidus*. *A. aconitus* larvae show a special predilection for *Eichornia speciosa* (water hyacinth).

Pistia, it would appear, affords anchorage to almost every species locally available, whereas *Lemna* is repulsive to almost all excepting *vagus*, *subpictus* and *hyrcanus* which also breed sparsely in open spaces where the plant is not thickly growing. More has been discussed separately on the ecologic relationship of this plant and also of two others, water hyacinth and alga, with the anopheline incidence of an area.

PISTIA.—A question was raised that *Pistia stratiotes* must invariably be associated with *philippinensis* breeding and a suggestion came that scrupulous cleaning of *Pistia* alone from watery areas would remove the vector species and malaria altogether.[29] We have seen before that quite a large number of species finds the plant a suitable associate and *Pistia* cannot claim to have such exclusive association with *philippinensis* alone. If any species could lay a claim on such an intimate association, it is the *A. ramsayi*. The *Pistia-philippinensis* bogey is founded on the belief that *Anopheles* requires more calcium which *Pistia* provides in the shape of calcium sulphate needles. These when ingested perforate the stomach wall of the larvae, and further, these perforations to help mechanical transference of the malaria parasites to the salivary glands through body cavity are retained in the adult stomach.[5] The idea is fantastic, for the digestive system of a larva is profoundly changed before it is transformed into the adult and undergoes complicated processes of histolysis and histogenesis. Furthermore, the perforations have no place in the completion of the life-history of the malaria parasites. Neither is the calcium requirement of *Anopheles* substantiated by facts. The calcium content of *Culex* mosquitoes reared from non-*Pistia* water on analysis was found to be of a much higher order than that of *Anopheles* from *Pistia* water.

Field experiments to remove *Pistia* in certain rural areas of the older alluvial zone of Bengal and of lateritic area were taken up to study the effect. This removal was not sufficient to eliminate the breeding of the vector species or of malaria in the environs.[56] Removal of *Pistia* has as much importance as clearance of aquatic vegetation has, as a general anti-larval measure : it is just a synchronism of vegetation clearance.

WATER HYACINTH.—Water hyacinth, *Eichornia speciosa*, has been found inhibitory to the breeding of *philippinensis* and *sundaicus* in Bengal when the water courses are densely covered by the plant. The absence of these two species in such situations does not so much depend on mechanical obstruction to oviposition or to respiratory difficulty of the larvae but to cutting off of sunlight by the plants and consequent destruction of the algae (*Enteromorpha*) and other appropriate vegetation (*Hydrilla*) so important for the growth of their larvae. This fact has led to the ill-conceived idea of utilising a thick coverage of this plant to control the breeding of the two species.[15] Almost the same effect can be obtained with any other plant when thickly grown on any water surface and the principle underlying this measure agrees in effect with the too well-known method of herbage packing in controlling anophelines.

Later work has failed to substantiate this method of water hyacinth coverage to control *sundaicus* in Orissa coast[23] and it appears that this is likely to cause more harm than good. A thick growth of the plant tells adversely on the composition of the water underneath making it extremely foul after sometime. If the plant is encouraged it not only would lead to domestic water difficulty in rural areas and an impediment to the growth of fish and blockage of navigation, but would actually induce more breeding of other mosquitoes particularly *aconitus* which finds the plant admirable for its development as already stated ; besides this would introduce the ever-increasing culicine menace. The idea of introducing water hyacinth to control anopheline breeding should therefore be discouraged.

ALGAE.—Importance of green algae and diatoms in the production of anophelines has long been recognised.[51] *Spirogyra* has a close association with *philippinensis* in Bengal as mentioned before, *subpictus* is equally involved.[45] Algae form the chief source of nutrition to the larvae and it has often been noticed that their removal automatically controls breeding. A close association of *sundaicus* with the floating algae *Enteromorpha, Oscillatoria, Oedogonium,* and *Lyngbya* has been observed ; in the absence of these algae the growth of *sundaicus* larvae is impeded.[42] The algae also help to protect the larvae from their predators.

The algae particularly the minute forms belonging to Volvocaceae and Pleurococcaceae are responsible for the breeding of anophelines in another way ; they generate enormous quantity of oxygen during the day-time as a result of photosynthesis.[11] This is very essential to aid respiration in clean water breeding anophelines. On the other hand, thick growth of *Microcystis* and a few other blue-green algae inhibits the breeding of anophelines.

VII. RICEFIELD BREEDING

The intensity of anopheline breeding in ricefields of Bengal varies in different localities within certain limits. Almost all the common species 11 or 12 in number including *philippinensis* may breed in these fields, but the breeding here is not always greater than in other types of water collections inside the villages ; it may be so in a few instances of course. With regard to *philippinensis* rice fields play a very minor rôle : most fields do not show the breeding and even if it is present, the incidence does not exceed 0·3 in 10 standardised samples against 10·6 in village ponds. In other words, the breeding of the species in ponds is over 35 times as great as that in rice fields.[47] *A. culicifacies* and *minimus* where they prevail are also not usually detected breeding in the ricefields, nor is *sundaicus* a problem of ricefields in the estuarine zone.[53] Ricefields therefore are not considered a danger malariogenically in Bengal.

A. hyrcanus the innocuous species constituting nearly 50 per cent of the total collection from ricefields at any time forms the bulk of the breeding. The maximum infestation of these fields occurs in September when *varuna* also has its peak prevalence. *A. annularis* breeds more intensively in stagnating water towards the end of rice season in January.

Rice plants 1′ to 2′ in height provide the best range for the development of most species. *A. philippinensis, pallidus* and *varuna,* three important species, seem to prefer breeding in fields with plants usually between 15″ and 18″ in height affording some shade. Beyond this height the anophelines become rare excepting *pallidus* which may breed until the plants reach a height of 2′6″.[47] The rice plants exert in two ways on the life of anophelines ; (1) by influencing the water temperature which in open spaces sometimes reaches 42°C or above in the afternoon, and (2) by regulating the growth of plankton specially algae like *Spirogyra* which is reduced in shade. More will be found on the effect of these two factors dealt separately under appropriate sections.

VIII. BIOTIC FACTORS

The larval incidence of a place is kept under check by a host of predatory insects, particularly Hemiptera and Coleoptera living in water ; the surface minnows also are considered as important in this respect. Dytiscidae, both larvae and adults, attack mosquito larvae. *Dytiscus* larvae are extremely voracious ; they pierce the skin of *Anopheles* larvae and suck the fluid by means of their long sickle-shaped and hollow mandibles which are pointed and perforated at tip. *Hydrophilus* larvae are even more voracious. They seize their prey and completely eat them up.[20]

Among Hemiptera, *Ranatra longipes* catches *Anopheles* larvae by pincer-like front legs and passes it to the rostrum and the feeding is completed in 8 to 15 minutes. *Sphaerodema annulatum* (Belostomidae) and certain Hydrometra are proved enemies of mosquito larvae. The bug, *Sphaerodema,* kills mosquito larvae by sucking their blood with the fine mouth-parts. A bug swimming about with a larva at the tip of the rostrum is quite a common sight if the two are kept together in a jar. After the body juice has been sucked the larva dead and empty is dropped to the bottom. Sometimes the whole body is reduced to fragments. It takes 6 to 8 minutes to suck a larva completely and then the empty skin is pushed out by the front legs of the bug.[48] Odonata nymphs are predatory but they mainly browse at the bottom and may not be so harmful to *Anopheles* larvae.

A few Molluscs may be of some use in making the water unsuitable for the growth of *Anopheles* larvae by emitting certain secretion from their body. *Rana tigerina* has also been reported as feeding on mosquito larvae.

Food contents in the stomach of four common fish in Bengal, *Aplocheilus* (=*Panchax*) *panchax, Barbus stigma, Esomus danricus* and *Colisa* (=*Trichogaster*) *fasciata* were analysed in their natural environment in order to find out how far they are responsible in the destruction of mosquito larvae.[40] *Barbus* and *Esomus* proved to be essentially vegetable feeders ; as such they do not seem to have any direct check on the larval population. *Barbus,* however, as in Java, may by its feeding on algae which provide sustenance to a number of anopheline species bring about a reduction of their numbers indirectly. *Colisa* may feed on insects but it is not a surface-feeder and naturally would not have much influence on the anopheline larvae. Only *panchax* showed some evidence of feeding on *Anopheles* larvae and eggs. Roughly 10 per cent of the *panchax* examined were found to have fed on anophelines.[40] Evidence however lacks to prove that this fish has a specific attraction for these larvae, but it seems to relish any food whether of vegetable or of animal origin. The cosmopolitan feeding habit of the fish finds support in the recovery of juvenile forms of *Vivipara bengalensis* from their stomach.

Microsporidia among protozoal parasites are known to cause a heavy mortality in anopheline larvae particularly during monsoon period. The genus *Thelohania* ranks highest in this respect. In Bengal we have been able to distinguish four of these, *Thelohania obscura, T. legeri, T. indica* and *T. anomala* as infesting larvae of *subpictus, vagus, ramsayi, annularis, hyrcanus, varuna* and *barbirostris*.[46] These parasites may be seen throughout the year but are more prevalent during April to September. Infected larvae look opaque in the thorax and abdomen in an advanced stage of infection and they become sluggish and eventually die within 2 to 6 days. Besides *Thelohania,* two other genera *Nosema* and *Plistophora* have also been recorded as parasitising mosquito larvae.[10]

Nematode worms of the genus *Mermis* are also known to parasitise both the larvae and adults of *Anopheles.* The infestation by these worms is also common during the monsoon months, August and September, in Bengal. The worms live in the haemocoele of the host insects and seven species, *hyrcanus, barbirostris, varuna, ramsayi, annularis, philippinensis* and *tessellatus* are known as vulnerable in the larval stage. Larvae infested by these worms which are 5 mm. to 8 mm. long do not appear to suffer considerably as they undergo the moults quite normally up to the last larval stage, but no further, when the worms emerge by killing the larvae.[10] Only one worm emerges from a host larva. The worm that attacks adult *Anopheles* is much longer and measures 14 mm. to 17 mm.; here also with the emergence of the worm the host is killed. Adults of *annularis* and *subpictus* are known to be attacked thus.

Several *Anopheles* both larvae and adults are susceptible to attacks by two species of *Coelomomyces, C. indiana* and *C. anophelesica.* A heavily infested larva is filled with numerous yellowish sporangia destroying the fat body, and its imaginal buds are suppressed. The larva is killed before pupation.[10]

IX. PHYSICAL FACTORS

TEMPERATURE.—Restricting effect of water temperature on the life of anopheline larvae particularly of *minimus* in the ricefields of Assam has already been studied. The restricted breeding of *philippinensis* also in Bengal fields appears to depend on this factor to a great extent. Towards the beginning of cultivation when shade is not sufficiently formed the temperature of the water in a ricefield often reaches 42°C or above towards the afternoon (3 P.M.) on clear days and is beyond the tolerance limit of the species mentioned. At such high temperatures (43°C or 44°C) species like *hyrcanus* and *vagus* can only survive. In Assam two more species *barbirostris* and *culicifacies* have also been found to survive this extreme temperature.[60] *A. subpictus* breeds freely at 32°C to 34°C,[21] and so do many other species.

There is a general agreement that *philippinensis* does not breed in shallow pools fully exposed to the sun or in absence of aquatic vegetation. This in fact supports the contention that water temperature which greatly rises under such conditions is a great limiting factor. The apparent discrepancy in the findings of other workers who consider that cutting off of sunshine is inhibitory to the breeding of the species melts away when we remember that their observations were based on deep water breeding where in the presence of submerged vegetation the sun is incapable of raising the temperature to the critical level. On the other hand, this favours the growth of plankton which in turn provides the sustenance to the species.

SHADE.—The shade affects larval growth in two ways: it helps decomposition of the vegetation growing underneath for want of sunshine and it prevents oviposition of females which often find the overhanging plants affording the shade an obstacle to reach water as proved for ***minimus*** in Assam streams[59] and for *culicifacies* in South Indian ricefields.[33] In partial shade the plankton particularly microscopic algae and diatoms may grow to provide food, but the water temperature which is raised to the critical level through the free play of sun's rays inhibits the growth of the larvae, whereas in dense shade although the water may remain cool enough the nutritive factor in the form of plankton becomes scarce for want of sunlight.

SILT.—The silt appears to be one of the limiting factors in deciding the breeding of anophelines in an area despite the finding in Assam that this has no lethal or larvicidal effect on *minimus* larvae.[61] Introduction of silt-laden flood water has produced effective result in controlling anopheline breeding although certain workers seem to think that the true cause for this inhibition of breeding does not lie so much in the silt as in the current that brings it. We have however pretty often seen that in rainfed ricefields where current is absent most species excepting the cosmopolitan *subpictus* and *vagus* would not breed after puddling which makes the water go turbid. But soon after the silt in the fields is deposited and the water becomes clearer other species like *hyrcanus* and *annularis* appear. Introduction of silt water from tidal rivers at high tides has always proved highly effective in the estuarine zone of Bengal in controlling the breeding of *sundaicus* in the borrow-pits along railway embankments, and so long as the silt remains the breeding is not resumed. Similarly in the deltaic zones the breeding of *philippinensis* in several ponds has been subdued by feeding them with flood water from the neighbouring irrigation channels.

WATER TABLE.—In Bengal it has long been recognised that in low-lying deltaic tracts a superabundance of surface water far from being harmful may exert a beneficial influence by covering the ground with a protective sheet of water.[2] This is explained by the fact that in heavy rains or in inundations the breeding places of anophelines are washed out and the aquatic stages of the mosquitoes do not get a chance to develop. This fact in essence led to the enunciation of the view that by raising the water table in an area with low subsoil water level the breeding of the vectorial species and consequently malaria may be wiped out in deltaic Bengal.[13] The soaking or submersion of soil in many instances is only relatively beneficial, and its real value must necessarily lie on the actual reduction which this measure brings about in the breeding of the vectorial species and on nothing else. It is certainly risky to assume that all watery areas thus introduced if allowed to continue long should always remain immune.

With respect to subsoil water table the different vector species exhibit a great tolerance and the same *Anopheles* can breed in such a wide range that a raising of the table in the normal way by irrigating the fields or by any other means is not likely to alter the breeding propensity very materially of the species. In the submontane zone for instance, the chief vector *minimus* breeds in areas in Teesta valley with the average subsoil water level at 16′3″ below the ground during dry months, whereas in the terai near Siliguri with the same species breeding profusely this level is only 6′ 9″ at the corresponding period. In the undulating deltaic areas to the west of the State where *philippinensis* and *culicifacies* are the predominating species the average subsoil water level varies from 18′ 1″ to 6′ 1″ and 39′ 1″ to 14′ 6″ in the wet and dry weather respectively in normal years. In Bengal plains, lower down the delta, where *sundaicus* appears to be the chief vector the subsoil water level varies from 4′ 7″ to 6′ 2″ in the different seasons,[57] and at the maximum level recorded here, we have already seen, both *philippinensis* and *minimus* in their respective zones would also breed.

The range of subsoil water level within which a species would breed is therefore so flexible that the idea of obliterating a species by the mere raising of this level, as advocated in certain quarters, seems highly inoperative. Water columns have been found to vary not only in the different topographical regions discussed here, but also within the same zone from place to place depending on the proximity to rivers and on the amount of rainfall.

The anopheline breeding in general at different depths of surface water shows that this is usually restricted to the depths from ½″ to 3′. But more frequently, provided there are no other detrimental factors, most clean water species, particularly *philippinensis* and *pallidus*, prefer to breed in water columns varying from 2″ to 1′ and anopheline incidence within this range is distinctly higher, almost double of that seen in any other column beyond this range at either end. A *vagus* has also been known to avoid a water column above 1′ in depth.[47] Apparently a very great depth of water is not liked by the anophelines, evidently for reasons of scarcity of supporting vegetation away from the water edges and owing possibly to the abundance of their natural enemies in deeper water or to other adverse factors like wave action.

X. CHEMICAL FACTORS

CHLORIDES.—Salinity plays a great rôle in the life of anophelines. It has already been pointed out that for *sundaicus* breeding a certain amount of salt concentration is essential and the best range appears to lie between 94 and 188 parts per 100,000 from samples of water round about Calcutta, and lower down the estuary the tolerance is higher reaching about 600 and above. The factor thus is highly variable with *sundaicus*, which at the other extreme would even breed in water with the chloride content as low as 16 parts per 100,000.[42] Whether the species breeding at such lower ranges can retain its vectorial status is however doubtful. Data collected from samples of water taken in course of actual breeding of *sundaicus*, and also before and after this, showed that the salt concentrations were regularly at a higher level during the breeding than when it was not.[49]

Within the range of tolerance exhibited by *sundaicus*, more usually towards the bottom, species like *subpictus*, *vagus* and *annularis* in the descending order may also prevail, whereas the factor has proved inimical to the growth of *philippinensis* mosquito. It stops breeding with the slightest rise in the chloride content in the normal habitat, particularly ricefields.[35]

HYDROGEN ION CONCENTRATION.—Hydrogen ion concentration indicates the favourable or unfavourable association of chemical and biological factors in the breeding places of anophelines and is no more than an indicator.[52] The pH value of waters providing the best breeding facility to a large number of anophelines appears to lie between 7·2 and 8·5. Only exception has been *minimus* which breeds in water below this range at pH 6·5 to 7·5. This indicates that the anophelines are mostly alkaliphile and avoid acid waters.

A. philippinensis finds a pH range of 7 to 7·5 most suitable in the districts of Bengal, and 7·4 proved the optimum for *subpictus* larvae.[21] In a series of observations the average pH came to about 8 or 8·2 for *sundaicus*[48] which seems to possess the highest tolerance to this factor.

The pH value over 8 indicates that the sample does not contain free carbonic acid but carbonates with or without bicarbonates. A value above 9 or below 5·5 seems detrimental to the growth of *subpictus* larvae[21] and perhaps of other allied species in the plains showing that extremes of both acidity and alkalinity are inhibitory to anopheline breeding.

CARBONATES.—Analysis of carbonates in the natural breeding waters failed to produce any evidence of the existence of a direct relationship between this factor and anopheline breeding. The carbonates detected did not show either any correlation with the pH factor, as it ought to show, since pH is closely interlinked with the presence or absence of carbonates in water. Further work is expected to throw more light on this point. The average reading for carbonates in the breeding places round about Calcutta particularly of *sundaicus* came to 13·4 ; the lowest detected was 4·2 and the highest 19·2. The figures only indicate, as in pH, that the anophelines of the delta are alkaliphile ; but there was nothing in the data obtained to suggest that the factor may be utilised in the determination of the specific nature of breeding in a place.

ALBUMINOID AMMONIA.—A large number of water samples from breeding places of areas in the suburbs of Calcutta was examined to find out the relationship of this factor with the prevalence of anophelines particularly *sundaicus,* the vector in the zone. On analysis it was found that a correlation exists between this constituent and the breeding of *sundaicus.* The species has always been detected when the albuminoid ammonia content of the breeding water was low compared to the figures obtained both before and after the breeding. The amount required was indeed very small and ranged from 0·006 to 0·04 part per 100,000.[49] With the lowering of albuminoid ammonia, free ammonia was found to increase and *vice versa.* Free ammonia was also present in traces usually in quantities below 0·01 part per 100,000, in a static water breeding mostly *subpictus* and *sundaicus.* Others like *culicifacies* avoid highly ammoniacal water[19] and are partial to organic pollution, so are *stephensi* and *varuna.*

DISSOLVED OXYGEN.—Investigations into the relationship of dissolved oxygen content with anopheline breeding in the ponds, tanks and ditches of Bengal proved that this factor though important has no absolute bearing on the breeding of the various species within the limitations normally present in such environments. The species *barbirostris, subpictus* and *varuna* have shown a tolerance for the oxygen concentration varying from almost 0 to 7 mg. per litre[11] in accordance with the varying breeding places when taken in the morning hours between 8 and 10. They are very little affected by the wide fluctuation in this factor in their habitat.

Somewhat different is the position with *annularis* which has a tendency to rise in frequency with a rise in the oxygen concentration until the peak is reached at 3 to 4 mg. ; after this the species declines again in density. *A. hyrcanus* and *ramsayi,* on the other hand, show a reverse effect ; their density which is highest at concentration of 1 mg. and below falls with the increasing concentration of oxygen in water.[11]

Oxygen toleration limits of different species discussed above lose their significance as a practical measure-stick when we consider that the content in a static breeding place in rural areas shows great diurnal fluctuation. This content in the same breeding area may rise from a low to the high value in course of the day depending on the sun ; the minimum concentration is reached at 6 in the morning and maximum at about 2 to 3 in the afternoon. With the cooling of water towards the evening and at night-fall the content falls again. But all these changes in the oxygen content of the breeding place do not cause any visible discomfort to the larvae; nor do they bring about a corresponding fluctuation in the larval incidence.

Despite the doubts raised in placing much reliance on this factor, some workers[6] consider that high dissolved oxygen content is a significant factor in the breeding of anophelines in a natural water. More work is desired to settle this point.

Finally, in the compilation of an account like this a good deal of foraging into others' works is imperative and it is possible that I might have omitted some ; for this which is not purposive I crave indulgence. Ecologists will perhaps find here a mere attempt to consolidate from fragments the existing knowledge of a group of insects which has been in the mind of mankind from the dawn of civilisation. No one is more conscious than myself that in this attempt there have been many a lapse, but if ecology means the study of relationship of organisms with their environment involving both intensive and extensive field observations on the natural history, we are no doubt trodding on the right path. The problems of ecology are diverse and the inroads to their solution are many. It has only been possible here to deal with a few important aspects of the innumerable problems of mosquito ecology, and if I have failed to give a more comprehensive picture, I expect at least adequate attention should now be focussed on the riddles and lacunae that await vigorous pursuing in this country. India as a tropical country with her varied animal life, no doubt, offers a much wider scope than most countries for the study of ecology and yet this fascinating subject has not advanced to the extent it has in Europe and America. Ecological studies imply not only spending long hours in the field facing the rigors of outdoor life, but often a close follow up in the laboratories as well for confirmatory tests. Obviously, one cannot be blamed for avoiding such hobbling pursuits, and maybe that has been the cause for the lack of buoyancy which is so much needed for such work. Science must progress, no matter howsoever the approach may be, smooth or ragged ; dauntless she goes in her forward march. Let us hope that realisation will dawn on us and the strive for knowledge and the spirit of achievement in the realm of animal ecology may not sag in us. Ample reward awaits those who would venture to dive deep and let me conclude with a plea for better and more active participation by our scientific workers in this discipline of zoology.

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SECTION OF ANTHROPOLOGY AND ARCHAEOLOGY

President :—DR. B. K. CHATTERJEE, M.Sc. (Cal.), D.Sc. (State) Paris

PRESIDENTIAL ADDRESS

RACIAL COMPONENTS OF THE TRIBAL POPULATION OF INDIA

It is my foremost duty to offer you my sincerest gratitude for the honour you have conferred on me by electing me to preside over the deliberations of the Anthropology and the Archaeology Section of the Indian Science Congress Association. I am fully conscious of my limitations, but I earnestly hope that I will get your full co-operation in course of our deliberations.

Before I proceed to discuss some problems of Indian Anthropology I would like to state briefly the general distribution of the tribes in India and also their linguistic and racial compositions.

In India, there are numerous tribes possessing different physical characters, cultures, languages and modes of life. The total number of the tribal population in India (according to Census of India 1951) is about 19,116,498 distributed over five Zones, *viz.*, Himalayan--Eastern, Central-Southern, Central-Northern and Southern and Western Zones. It may not be out of place to mention here some of the important tribes of the zones mentioned above.

1. In the Himalayan-Eastern zone, we find the following tribes:
   (*a*) Garo, (*b*) Khasi, (*c*) Naga, (*d*) Abor, (*e*) Dafla, (*f*) Tagin, (*g*) Galong, *etc.*
2. In the Central-Southern zone,
   (*a*) Gadba, (*b*) Parja, (*c*) Gond, (*d*) Kol, (*e*) Pardhan, *etc.*
3. In the Central-Northern zone,
   (*a*) Kisan, (*b*) Lohara, (*c*) Malpaharia, (*d*) Munda, (*c*) Santal, *etc.*
4. In Southern zone,
   (*a*) Chenchu, (*b*) Kadar, (*c*) Kanikkar, (*d*) Muthuvan, (*e*) Palliyan, (*f*) Urali, (*g*) Kuravan, *etc.*
5. In Western zone, we find the following tribes:
   (*a*) Bhil, (*b*) Dhulia, (*c*) Dubla, (*d*) Gamta or Gamit, (*e*) Varli, (*f*) Nayak, *etc.*

LANGUAGES SPOKEN

There are about 30 different groups of spoken languages and each group consists of one to five or more different dialects. About half a dozen of these belong to the family of languages known as Austric which is very widely distributed and might be the earliest family of languages spoken in India. Since the Indo-Austric speeches are divided into two sub-groups, Kolarian or Munda and Khasi, some are of the opinion that there had been two routes of migration, one from the West and the other from the East of the Himalayas. In the former case the languages are now known as Munda or Kolarian spoken in Central India, and the latter is termed as Monkhmer, spoken by the Khasis of Assam. It should be remarked that the Nicobarese of the Nicobar Islands also speak a language which bears affinities with the Eastern branch.

The Sino-Tibetan languages also fall under two groups, Tibeto-Burman and Sino-Burmese, the Himalayan and the North Assam tribes speak the former, the Kachin and Kuki-chin tribes belong to the latter sub-group and the Naga speeches belong to an intermediate position. Though the Kuki-chins are Indian tribes, they are racially and culturally more linked with the people of Indian Archiplego and the tribes of the Pacific Islands. Dravidian languages are spoken not only in South of Godabari but also among the Brahui in the isolated places of North West and Maltos in the Rajmahal Hills.

The European languages subsequently infiltrated into India due to invasions on a small or large scale, between 1500 B.C. and the beginning of Christian Era. It would appear from the historical records that the Persians and Greeks and after them the Sakas or Scythians and the Kushans came from Central Asia and later on, about 5th century A.D., another horde of people known as the Huns invaded North India from Central Asia. About 8th century, the Muslims appeared and continued their inroads until the establishment of the Mughal Empire in India in the 16th century A.D. By that time the Portuguese had already settled in Goa.

DIFFERENT THEORIES REGARDING THE RACIAL ORIGIN OF THE PEOPLE OF INDIA

In the opinion of some anthropologists the oldest stratum of India's population is Austro-Asiatic, or Proto-Australoid in origin. These people are long headed, dark skinned and broad nosed. Their physical features are still to be found among the tribal population of Chotanagpur and Central India. According to Hutton, these proto-Australoids came to India from the East. The people had long head and were matrilineal in descent. Apart from these, a round headed Armenoids had also penetrated into India from the Asia-minor, Mesopotemia, *etc.*, *via* Persia. The people in the Himalayan-eastern Zone are Mongoloid either of the tall Tibetan type or of the shorter and darker Burmese type. According to Buxton some of Risley's Mongolo-Dravidian groups are the variations of the Parrorean race which was termed by Haddon.

Sir Arthur Keith on examining the Bayana skull opined that although the distinct age of the skull was uncertain, still it appeared to be of considerable antiquity as judged by the degree of mineralization. The cranial shape is long and disclosed undoubtedly Mediterranean affinities with which others do not agree. Other accounts on pre-historic skulls are given by Sewell and Guha particularly on the skulls excavated at Nal and Mohenjodaro. Having examined these skulls, Sewell and Guha and later Guha and Basu pointed out that during the Chalcolithic period in Indus Valley and in Beluchistan, it appeared that the racial types were similar to those excavated at Kish and Al'ubaid in presargonic Sumaria and consisted of Mediterranean strain. They are long headed types probably of proto-nordic affiliation along with plano-occipital broad headed race which is the characteristic feature of the people of Asia-minor at the present time. Elliot Smith on examining the Adittanalur skulls, excavated by Rea in 1901, fuller details of which were published by Zuckerman, stated that the Australoid character of one of the skulls was confirmed. Turner and Basu examined certain modern skulls of Central India and Chotanagpur and noticed the presence of Australoid character in some of them.

On the basis of certain somatometric data, Risley propounded a theory and classified the people of India as follows:

1. Turko-Iranian type represented by Baloch, Brahui and Afghans of Chitral and North Western Frontier Provinces which are now in Pakistan.
2. The Indo-Aryan type occupying the Punjab, Rajputana and Kashmir having its members, the Rajputs, the Khatris and the Jats.
3. The Scytho-Dravidian type of West India, comprising the Maharastrian Brahmins, the Kumbis and the Kurgs probably formed from a mixture of Scythian and Dravidian elements. The former element predominated in the higher groups while the latter one predominates in the lower.
4. The Aryo-Dravidian type to be found in Uttar Pradesh, in some parts of Rajputana, in Bihar and in Ceylon and also present among the high caste Brahmins, as well as among the low caste people, viz., the Chamar.
5. The Mongolo-Dravidian type of lower Bengal and Orissa found particularly among the Bengalee Brahmins and Kayasthas, having a strain of Indo-Aryan blood in the higher group.
6. The Mongoloid type of the Himalayas, Nepal, Assam and Burma represented by the Kanets of Lahul, Kulu and the Lepchas of Darjeeling, the Limbus and the Gurungs of Nepal and the Bodo of Assam.
7. The Dravidian type extending from the valley of the Ganges down upto the whole of Madras, Hyderabad, Central Provinces and Chotanagpur.

Sir William Crooke and Thurston following Risley's lead worked among certain people and on certain gloceries of tribes and castes living in the United Provinces and in Southern India, respectively.

Von Eickstedt attempted to reconstruct the racial history of India as a whole and found that Veddid of the primitive jungle folk, *viz.*, Gondid or dark brown wavy hair race, Malid or black brown progressive people of Southern planes who are again made up of, Southern or Tamilid and Northern Deccanid or Kolid races, and lastly the progressive new India or Indid group divided into (*a*) brown and (*b*) graceful and coarse light brown, North India types. Of these, the Melanid race is the oldest and the descendent of the Indo-Negroid or Eastern branch of the group of Negro races. It may now be described as belonging to the frinze of the Negroid and Europid races.

A different racial reconstruction was attempted by Guha on the basis of his original somatometric data taken on different tribes and castes of India. Guha opined that there was a short dolichocephalic strain with high headed and moderately broad nose, over which was superimposed a brachycephalic race of mostly plano-occipital type in Western and Eastern India, and a proto-Nordic type in North Western India. In addition, the tribal group definitely revealed a Negrito strain now mostly submerged in the proto-Australoid element, which in combination with various other strains made up the aboriginal population of this main land, *i.e.*, excepting those who are living in the sub-Himalayan regions and Hills of Assam, where the Mongoloids, both long headed and broad headed tribes, form the chief constitutent of the population.

According to Guha racial elements came from six main racial types having 9 sub-types which are as follows:

(1) The Negrito, (2) The Proto-Australoid (3) Mongoloid consisting of Palae-Mongoloid of long headed and broad headed types and the Tibeto-

Mongoloids ; (4) the Mediterraneans comprising of Palae-Mediterranean, Mediterranean and the so-called oriental types ; (5) the Western Brachicephal consisting of the Alpinoid, the Dinaric, the Armenoid and lastly (6) the Nordic type.

SEROLOGICAL STUDY

As regards the Serological study, L and H. Hirschfald were the first biologists to study the Indian blood groups. They examined blood samples of 1000 Indian soldiers in Macedonia during the first World War and found that the high percentage of group B exists among them. Unfortunately, the sample examined by them was a Hetorogeneous one composed of Gurkhas, Gharowals, Jats and Rajputs. Then we find Malan, and Lahiri also carried on serological tests among the Rajputs and mixed Hindus from the United Provinces, from the Dravidian people, and Tea garden labourers of Chotanagpur belonging to different castes and tribes, all lumped together. McFarlane, Sarkar, Aiyappan, Majumdar and others also surveyed blood groups of different tribes and castes of India. The result of these reports regarding the blood groups in India does not warrant us to draw any far reaching conclusion, since the materials on the ethnically separated groups of this country are not sufficient.

Blood grouping tests have been done mainly in ABO system but no reliable worker has yet completed the test in M., N., system. As far as Rh system is concerned, Khanolkar and Sanghvi have tested and carried out the Rh tests in a few Hindus, Parsis and the native Christians. But all the Hindus were Rh positive. It is not known whether the Rh positive belong to Rh^O, Rh^1 or Rh^2. It is difficult to judge the affinities of the Indians to the white, the Negroid or the Mongoloid races.

On the basis of the somatometric data collected by me particularly on the Kols of Central Provinces, Santals of Santal Parganas and the Kanikkars, the Uralis, the Muthuvans, the Malapantarams, the Kuruvans, the Paliyans and the Mannans of Travancore-Cochin and the systematic analysis and comparison of those data, the following results were arrived at.

THE KOL OF MADHYA PRADESH

The following account is based on the somatometric measurements and observations made by me on 127 adult male and 24 female Kols of Central Province and on adult males of the following tribes, *viz.,* the Urali, the Malapantaram, the Paliyan, the Kuruvan, the Muthuvan, the Kanikkar and the Mannan of Travancore and Cochin State, apart from the somatometric study of the Santal of Santal Parganas. Out of these tribes, I would like to deal with the Kol of Central Province in detail.

The techniques advocated by Manoco, 1906 and the Geneva 1912 and the subsequent modifications were followed in taking somatometric measurement. All the measurements are given in millemeters and were taken by the instrument manufactured by Messrs. Herman Rickenbach and Co., at Zurich.

Dalton[1] records a tradition connecting the Kols with the Cheros, who prior to the Aryan occupation of the Gangetic Provinces were the dominant race in Gorakhpur, Behar and Shahabad and surmised that the now despised Kol was in those days the language of that part of India.

The modern province of Behar anciently known as Magadha, has numerous antiquities attributed to the Cheros and Kols, and from the legends handed down, it appears that the sovereigns of the country at one time was the Cheros, the people in most of these parts being the Kols.

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[1] Dalton, E. T.—Descriptive Ethnology of Bengal, p. 151, Calcutta, 1872.

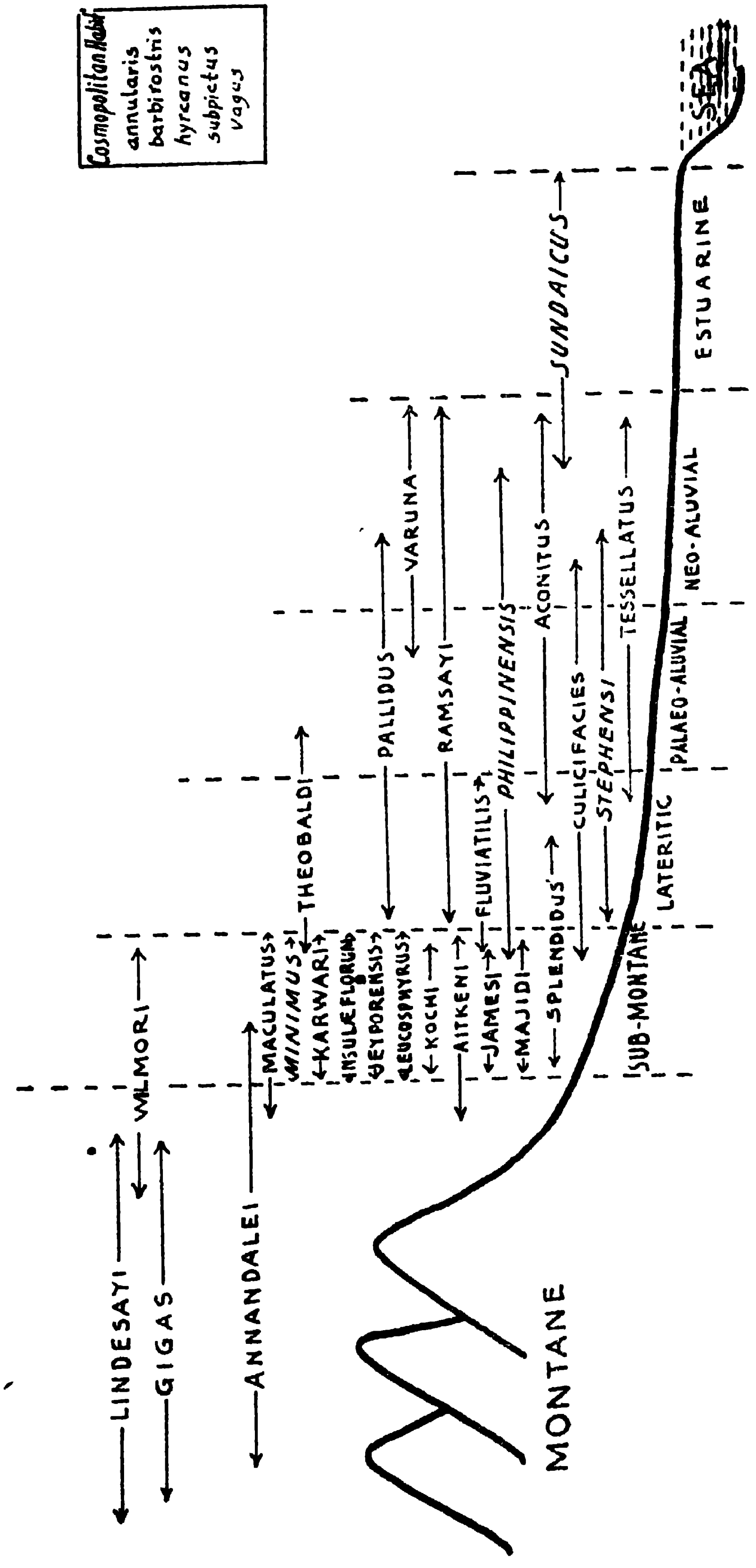

FIG. 1. Diagrammatic representation of the different zones of Bengal with their anophelines.

at high altitude. The subgenus *Myzomiya* is strikingly absent in this zone and the preponderance of alpine oriental species is the rule. But if the forests are cleared and open tracts with slow-running streams are available the species *minimus* makes its appearance and continues to breed there so long as the conditions prevail.

A. stephensi of which both the type and *mysoriensis* forms are prevalent in Calcutta notwithstanding the solitary record of its incrimination with malaria transmission[55] has not given any cause of alarm. The extremely rare manifestation of the species in hand catches from dwellings in Calcutta indicates lack of dynamics of the species,* or that the adults do not normally take to indoor shelters.

The vectors, as we have seen, are distinct for a zone and rarely would two of them occur at any one place and time, but where such events happen the species primarily responsible for malaria transmission excels the other by no less than 30 to 50 times numerically.[26]

III. SEASONAL INFLUENCE ON ANOPHELES

The general environment varies within a given region and the local distribution of a species is controlled by reactions to the environmental differences among the available range of habitats. The seasonal variations in anopheline density give us a method of approach to the ecologic relationship of different mosquito population. The variations studied were based on standardised capture of diurnal mosquitoes from collecting centres and in box traps at night. Mosquitoes per catching area have been used for study of fluctuations in density during the various seasons.

A. subpictus has the maximum prevalence during the dry weather, once from April to June and again during November to December, and drops with the onset of rains ; whereas *vagus* has its peak during the rains from July to September or even October if rains continue. Both *hyrcanus* var. *nigerrimus* and *barbirostris* may prevail during the rains, but there is a peak also during December to February ; they are extremely rare during the period April to June.[12] *A. varuna* is usually most prevalent during August to October when the atmospheric temperature is about 87°F or 88°F and the humidity 75 to 80 per cent. It prevails within a very small climatic range and drops with the onset of cold weather.[35 38] *A. aconitus*, on the other hand, prefers the cold weather showing its maximum prevalence during January to March and disappears with the rise of temperature. *A. annularis* also has its peak almost about the same time but the ascendancy starts from December. May and June appear to be the lean period for the last three species. *A. sundaicus* shows its maximum incidence during September to December, and there may be another short rise in May when there is a little rainfall mellowing the temperature to some extent. The best temperature range for the species appears to be 80°F to 90°F when the relative humidity averages between 65 and 84 per cent. *A. philippinensis* likewise appears essentially an autumnal species with the maximum prevalence during August to December having almost analogous temperature and humidity factors as those of *sundaicus*. In certain badly infested rural areas the species may trail on to March.[47] *A. ramsayi* appears in large numbers during August to November or December when the temperature varies from 80°F to 90°F with the humidity at 65 to 88 per cent. *A. pallidus* is mostly seen in December, and *culicifacies* during March-April and through July if there is a late rain, when the temperature varies from 90°F to 95°F with the humidity at 70 to 75 per cent.[55] *A. minimus* has its maximum incidence during September to November and again in April-May when the winter is over. The mean maximum temperature at the first peak varies from 77°F to 90°F, and this may rise in spring to 85°F to 90°F. The humidity for the corresponding period differs very little, 84 to 90 per cent in the autumn and 75 to 85 per cent during April-May. The maximum density of *stephensi* is noticed in July-August at the temperature of 85°F to 90°F and at 85 to 90 per cent humidity.

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* Calcutta receives anti-mosquito measures : the low incidence of the species may be partly due to these.

The two climatic factors, temperature and humidity although differ among the various species, overlapping of ranges is also not uncommon ; and a digression from one range to another is not always inimical.

One other factor, the rainfall, appears to bear a closer association in determining the seasonal distribution of the different species, no doubt, by affecting the larval life and habitat more directly. Both *sundaicus* and *philippinensis* find a rainfall of 3″ to 7″ during a month more congenial to raise their number.[38] *A. subpictus* also finds a similar range 4″ to 8″ good for it. *A. culicifacies* prefers a range of 5″ to 10″ of rainfall, and *ramsayi,* a range of 7″ to 10″. A rainfall of 7″ to 8″ seems favourable for *varuna* and 10″ or so detrimental to the species. *A. vagus* likes 8″ to 12″ of rainfall, while *stephensi* 10″ to 12″ or more. *A. minimus* requires the heaviest rainfall ; from 16″ to 40″ is the favourable range and at about 10″ the number falls.[57] Consequently the species becomes rare from January to March or April when the rainfall is virtually absent, or at the most not exceeding 3″ or 4″ in any one month even if it rains.

IV. ADULT BEHAVIOUR

EMERGENCE : The time of emergence is of special interest in anopheline ecology ; the ease with which mosquitoes can infest our dwellings depends on this to a great extent. The imago immediately after emergence cannot fly. Its wings have to dry and harden and this takes different time in different species. *A. annularis* takes about 1 to 2 hours to emerge from the pupal case, while *barbirostris* may perform this function in 8 to 30 minutes[16] They are vulnerable to their predators, such as, the water striders and other larger Hemiptera and a few other insects, and surface feeding fish like. *Aplocheilus* at this stage. The maximum emergence of most anophelines occurs during the dark hours of 6 to 9 P.M. when about 50 per cent of the total mosquitoes in a brood emerge. In *culicifacies* and *hyrcanus** maximum emergence has been noticed between 9 P.M. and midnight. This behaviour of night emergence confers a special advantage to the mosquitoes in escaping their day-time predators.

A. stephensi seems to be an exception in this respect in having an emergence time between 3 and 6 P.M. The almost complete failure to make day-time collections of the species in Calcutta by several workers possibly depends not in a small manner on this interesting diurnal emergence when their lodgement into rooms would be highly unprofitable on account of severe competition from spiders and geckoes. This takes us to another problem, the question of preferential resting habit.

SHELTERS : We no doubt know the day-time resting places of some anophelines, but a large number has yet remained a guess work. Certain species, particularly *culicifacies* which is a vector elsewhere seems to have a special attraction for cattle sheds in Bengal like the innocuous

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* In Bengal *hyrcanus* refers to *hyrcanus* var. *nigerrimus.*

barbirostris, hyrcanus, subpictus, and *annularis.* On the other hand, three of our efficient vectors mentioned above, *minimus, philippinensis* and *sundaicus* are essentially a house frequenter: twice as many adults have freely been captured from dwellings as compared to those of cattle sheds.[14] The position on the wall surface that the different species take up while resting is another interesting feature. *A philippinensis,* for instance, rests very close to the floor within 1′ to 1′6″ from the ground level of rooms. The species has also been found resting on sooty pots and other utensils usually seen lying on the floor of kitchens in the rural areas of Bengal.

With regard to *philippinensis* doubts have recently been raised as to the merit of the day-time indoor catches of the species[50] which has been known resting among outdoor vegetations in other countries,[16 66] and we are more inclined to the belief that a large population of this mosquito in recent years has been resting outside after feeding in our areas also. The sparse representation of the species in routine catches even from endemic areas where this has been the established vector lends support to the view.

Besides houses and animal sheds, boundary walls, crevices and hollows in outdoor walls, culverts, tree trunks and shaded banks of streams, reeds and grasses are also utilised as resting places.[30] We have already referred to the extreme paucity of *stephensi* mosquito in rooms. The adults, however, have been known from outdoor shelters, such as, the overhead unfiltered water storage tanks of galvanised iron which gets so heated during the afternoon that life becomes perilous in such a precarious shelter.

When the total annual catches from the deltaic tract where *sundaicus* is the vector are analysed in terms of percentage infestation between this and two other associated species, *annularis* and *hyrcanus,* the *sundaicus* is excelled in density in bed rooms by *annularis* only. But in cattle sheds the *sundaicus* happens to come at the bottom.[39] The *annularis* taking a top position in bed rooms, however, cannot numerically surpass the cattle shed catches. All these are highly suggestive of the dissimilar feeding habits of the species encountered.

FEEDING HABITS.—Males, as is well-known, feed only on vegetable or fruit juice in nature and are non-biters. Most female anophelines, however, feed readily on blood 48 hours after emergence. But not all feed on human blood normally. Uses of traps with animal baits and of precipitin tests have proved that the species concerned in malaria transmission, *minimus, philippinensis,* and *sundaicus* have a high anthropophilic preference. As much as 86 to 94 per cent of *sundaicus* and 89 per cent of *minimus* mosquitoes in wild catches may contain human blood.[63 64] But others, *maculatus, hyrcanus, kochi, subpictus, vagus, annularis* and *splendidus,* essentially feed on cattle blood ; their stomachs do not show human blood in more than 10 per cent instances. In *stephensi* of Calcutta this index was even lower at 3·5 per cent.[28] At the same time *subpictus* showed an index of 25 per cent[27] which is much higher than the expected figure elsewhere : the dearth of cattle in the area must have helped to divert the species more and more towards human shelters, and a rise in the anthropophilic index is the logical outcome. The same has probably happened with *culicifacies* which in areas where it is not a vector may show an index of 27 per cent.[34] But both *culicifacies* and *stephensi* are not very abundant in Bengal and their anthropophilic indices reported are only relative. *A. leucosphyrus* which is one of our hill species may show a high anthropophilic index, as much as 75 per cent.[22] This species should be looked on with concern, particularly as it has been proved a vector[4] in regions of Assam.

That many species are not highly sensitive to their blood feed, and can take over to alternative sources, have very cogently been reported from Indo-China where ***minimus, maculatus, jeyporiensis*** and ***hyrcanus*** show in the absence of cattle a high incidence of human blood (89%) in the stomach, but in their presence the index may be as low as 8 per cent.[63] Even *minimus* which is so perfectly a homophilic species in India would adapt to buffaloes.

The maxillary indices also afford some clue as to the feeding habits of the anophelines, but as a criterion of pathogenecity these are not considered as absolute and not as reliable as the other methods just mentioned. The zoophile species have multidentate maxillae as in *hyrcanus* and *vagus* with the indices at 15·7 and 14·2 respectively.[8] The paucidentate maxillae are seen in anthropophilic species, such as *minimus* and *jeyporiensis* which have low indices of 11·3 and 11·9. *A. aconitus* with an index of 15·5 in India is another example of multidentate zoophilic species.[54] The records cited so far compare admirably with the two types of feeding habits discussed here. But an ecologic variance challenging the validity of the assumption has also been reported from Indo-China where *aconitus* although a zoophile like the Indian strain has however paucidentate maxillae with an index of 11·2.[9] Paucidentate condition should not therefore be always considered as an indication of anthropophilism, neither is multidentate probably a certain pointer to zoophilism.

SEX RATIO.—The sexes on emergence are not always equal.[3] In most species the females usually constitute 60 per cent of a population in bred specimens, or in other words, the sexes are represented in the proportion of 2 males to 3 females.[36] But if only the dry weather emergence is considered the sexes may appear on a 50 : 50 basis. This has been specially found in *sundaicus* during the period February to June. Similar seasonal fluctuations in the sex ratio have also been noticed in *annularis* and *culicifacies*[17] But when the rains set in and in cold weather the females again rise in number giving them an ultimate overall preponderance as stated above. One interesting observation has been that the output of males may be increased if the larvae are fed on a protein diet in the shape of crushed fly or reared in natural breeding waters,[17] evidently rich in zooplankton.

Among wild caught anophelines, on the contrary, the males seldom exceed 10 per cent of a year's catch indoor as in *sundaicus,* usually less : the exceptions being *subpictus* and *vagus* with the figure at 20 per cent.[39]

MATING.—Mating in small cages under laboratory conditions among anophelines has been almost impracticable. We have so far failed to get any satisfactory evidence of the occurrence indoors excepting perhaps in *stephensi* which seems to adapt itself readily to laboratory culture.[32] The nearest homely atmosphere that would satisfy these insects, particularly *culicifacies,* for swarming and mating seems to be an insectary of the size 10′ high and 40′ × 20′.[34] It was not possible to induce mating in *minimus* in a cage measuring 2′ × 2′ × 2′, but *fluviatilis,* a related species, could be made to do so in presence of blue light.[18] The nature and intensity of light therefore appear to play a very important part in this respect more than the space.

Whatever records we have, lead to substantiate the view that nuptial flights are best accomplished outdoor at dusk when darkness has fallen over earth. Swarming takes place more often near the breeding places as seen in *sundaicus, subpictus* and *vagus* over the salt lakes near Calcutta. Nevertheless, the sexual urge is so great with them that they would undertake a long flight even up to 2 miles to perform the function as the reported swarming of ***sundaicus*** and ***subpictus*** off the Chilka lakes in Orissa coast would tend to indicate.[24]

Cross-mating has been recorded between ***subpictus*** and ***vagus***,[37] and the phenomenon is probably more common than is usually believed. The hybrid generation with the ***vagus*** character dominating as a result of crossing between these two species would interbreed with pure ***subpictus*** and to all evidences the resultant progeny would comprise 50 per cent of each type, *vagus* and ***subpictus***, following the principle of true Mendelian segregation. Successful cross-mating between *A. gambiae* and *A. melas* has also been reported from Africa,[62] and the phenomenon is too well-known in *A. maculipennis* of Europe.

FLIGHT RANGE.—Not much work has been done to determine the flight range of mosquitoes in this country. But from scrappy reports it appears that most species do not fly out far from their site of oviposition if food is available close by, at least that holds good for ***annularis, hyrcanus, barbirostris***, *varuna*, *aconitus* and *ramsayi* as observed in our studies. Although *varuna* is unable to fly long distances, its near ally ***minimus*** in other areas can fly with ease a distance of one mile,[7] and so can ***culicifacies*** in South India when in need of food [31] ***A. philippinensis*** and ***pallidus***, like *fluviatilis* and *maculatus* would not, as a rule, fly out over ¼ to ½ a mile in India, although the last-named species in Malaya has been known to cover a distance of 1¾ miles.[65] The longest distance covered by Bengal mosquitoes in dispersal has been noticed in *sundaicus* which could be recorded in areas nearly 3 miles out from its possible breeding site. My record shows, contrary to popular views, that the males of the species do not lag behind their consorts in this respect. We have however failed to establish whether this distance is completed in one straight flight or in relays. Some of the long distance fliers from outside India are *A. quadrimaculatus* of America covering 1½ miles, *A. funestus* of Africa with a 2-mile range and ***A. maculipennis*** of Europe, perhaps the toughest species, with its flight record of 4 to 6 miles.

The flight range not only varies with different species but may also change within the same species from place to place, for although in Calcutta *stephensi* seldom travels, in fact the species does not want to stir out from its domestic assignments, this in other parts has been known to fly out 1½ miles.[1] The principle underlying this variation in the flight behaviour seems to depend not on one factor, the search for food, but on a group of complex environmental factors: food, mating and an inner urge for dispersal.

TRANSPORT.—Apart from voluntary flights in search of food or favourable breeding sites, the anophelines have been known to be mechanically transported through shipping, locomotives and country crafts, and this has been one of the most common ways of colonisation of species in distant areas. The instance of ***sundaicus*** invasion in Bengal has already been cited. The species was not known causing havoc anywhere nearer coastlines of India beyond Andamans in 1912.* From this date to its inland recovery at Port Canning and Budge Budge (Bengal) in 1930 must have been an unwritten history of continuous assault by the species to colonise the virgin swamps lying behind ***Sunderbans***, and the only possible route of travel during that period appears to be the sea, and country crafts on merchandise must have been extensively used in this attempt. A recent study has revealed unfailingly that this was the agency employed in their next hop from Port Canning and the *Sunderbans* to the environs of Calcutta. Nearly 4 per cent of country boats carrying cargo to Calcutta were infested with *sundaicus* which had been picked up *en route* while passing through *Sunderbans,* lower down.[44] These mosquitoes subsequently dislodged themselves at the salt lakes to the east of the city of Calcutta when the boats were being detained for checking up at the toll points adjoining the lakes. Considering the huge river traffic, Calcutta has to face every year this percentage infestation amounted to a number not inconsiderable. The species along with *subpictus, vagus* and *varuna* was found sheltering in such cargoes as straw, jute and paddy (unhusked rice) among others.

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* Earlier records by Gravely from Port Canning in 1910 and by Brahmachari in 1912 from a Calcutta tank are doubtful cases.

The railway traffic from the south converging to Calcutta was responsible in no less a manner in this inland invasion of *sundaicus,* and nearly 15 per cent of the incoming trains were importing the species at one time. This was the *modus operandi* of the species in its attempt before it finally succeeded in settling round the city during 1934 to 1936.[41] Ten more common species including *philippinensis* and *stephensi* were being transported in the same way through the railway traffic, but in insignificant numbers.

V. LARVAL HABITS AND HABITAT

In the montane areas of Darjeeling district the main breeding places are *jhoras* (streamlets), seepages, drains, puddles and borrow-pits. In the submontane zone, *jhoras,* canals, streams, river beds, *jheels* (lakes) and borrowpits are the chief sources. In the upper deltaic zone the breeding sources are the neglected ponds, tanks, dying river beds, irrigation canals, borrow-pits etc. In the estuarine zone, the tidal creeks and ditches, canals, and series of borrow-pits along embankments fed by tidal waters, as also swamps formed by silted up river beds constitute the menace.

HILL STREAMS AND JHORAS.—*A minimus* the most important species in the montane and submontane zones breeds in slow-running streams and *jhoras* (streamlets). *A. lindesayi* and *jamesi* have not been found to breed anywhere except in the *jhoras* and drains. *A. maculatus* likes the same habitat as *minimus.* In *jhoras, maculatus* has been known to constitute 30 per cent of the total collection, while *minimus* 12 per cent.

RIVER BEDS.—In the lateritic moor countries in upper deltaic zone the pools formed in dying or drying river beds provide suitable breeding forum for species like *culcifacies* and *stephensi* when the water is fairly clear. But in many dead rivers with profuse vegetation *philippinensis* is often found along with *aconitus* and a few other common species.

PONDS AND TANKS.—*A philippinensis* mostly breeds in ponds and tanks overgrown with the appropriate vegetation, submerged and floating, in rural areas of the plains of Bengal. *A. hyrcanus, barbirostris, subpictus, vagus, annularis, pallidus, ramsayi,* and *varuna* are also fairly common in tanks and ponds.[45] *A. culicifacies* is seldom recorded from such places. Old disused and neglected ponds are the most favourite breeding places in rural areas.

WELLS.—Open wells in submontane zone often breed *minimus* and *maculatus.* In the deltaic zones these may provide breeding facility to *culicifacies, stephensi* and *varuna.* Other species like *hyrcanus, subpictus* and *annularis* have also been found to breed occasionally, but the breeding is never intensive.[57] The wells when in constant use are not so suitable for breeding purposes.

ARTIFICIAL CONTAINERS AND CISTERNS.—*A. stephensi* in Calcutta invariably breeds in the defective overhead tanks of unfiltered water without any evidence of floatage on surface. Other containers like concrete underground cisterns and receptacles used by masons for soaking bricks and abandoned pans and pots and rainwater puddles may also show the breeding of the species[25] along with the ubiquitous species, *subpictus* and *vagus*.

SALT WATER POOLS.—*A. sundaicus* breeds in pools which are touched by the spring tides and in those formed by percolation of salt water through embankments of tidal channels. It appears to be absent from places where the tide runs in and out freely. The flow of water when obstructed by *bunds* (dikes) and locks creates the most favourable condition for the breeding of the species in the estuarine zone. A salinity over 0·1 per cent and a trace of nitrite to indicate organic pollution seem a desirable set-up for its breeding. Other species associated in such environments are *subpictus, annularis,* and *vagus* if the salinity is not excessive.

The tides penetrating inland into low-lying areas have in course of time lost their flow back as silt deposited on the mouth, and the water thus accumulated has been broken up into innumerable fish ponds and *bheries* or shallow watery areas by short embankments. These constitute the most formidable breeding places of *sundaicus* in Bengal.

IRRIGATION AND NAVIGATION CANALS.—In the submontane zone the irrigation canals provide good facility for the breeding of *minimus* and *maculatus*. In the upper deltaic zone these canals when the flow is insufficient show the breeding of some common species of which *annularis* and *vagus* together constitute nearly 50 per cent of the total collection.[57] In the lateritic country to the west of the State *culicifacies* may breed in such places. The navigation canals in lower deltaic zone frequently furnish breeding facility for *sundaicus* particularly when the lock gates at the mouth of the canals remain closed for sometime impeding the free flow of tidal water. *A. stephensi* has also been recorded at times from such canals along with a few more common species, *subpictus, barbirostris* and *annularis* when the water stagnates.

BORROW-PITS.—In the borrow-pits in montane zone along highways and railroads *maculatus, minimus* and *kochi* would casually breed, although these by no means constitute the normal habitat of the species. *A. subpictus, vagus, hyrcanus, annularis* and *varuna* are usually recorded from these pits in the deltaic zone when vegetations appear in them. In the lower Bengal with tidal influence the borrow-pits, particularly along the railway embankments, have often been the favourite breeding site of *sundaicus*. We have so far no records of *philippinensis* or *stephensi* breeding in such sites. In the plains *vagus* has been known to form 50 per cent of the total catch from borrow-pits, *hyrcanus* following next with 28·8 per cent.

VI. AQUATIC PLANTS AND ANOPHELINE BREEDING

A study of the association of different aquatic plants with the breeding of the various anophelines comprising a dozen species, in the plains of Bengal has revealed that the larvae of *philippinensis* among others were associated with almost all types of plants studied excepting *Lemna* (duckweed) ; but the species was most frequently associated with the alga *Spirogyra* sp. in common with *subpictus* larvae. Larvae of *ramsayi* were almost exclusively associated with *Pistia stratiotes* (water lettuce) ; their association with other plants was almost negligible.[45] This association yielded on an average 3·6 larvae and 0·9 adult of *ramsayi* per observation. *A. hyrcanus* while showed a disliking for *Ceratophyllum* and *Hydrilla* was not averse to *Pistia*. Waters with *Hydrilla verticillata* and next to this with *Ceratophyllum demersum* were most associated with *annularis*. The high incidence of 14·6 larvae and 3·1 adults of *annularis* per observation was noticed from this association. *Utricularia* as supposed is not always detrimental to anopheline breeding and the plant has a close association with *pallidus*. *A. aconitus* larvae show a special predilection for *Eichornia speciosa* (water hyacinth).

Pistia, it would appear, affords anchorage to almost every species locally available, whereas *Lemna* is repulsive to almost all excepting *vagus*, *subpictus* and *hyrcanus* which also breed sparsely in open spaces where the plant is not thickly growing. More has been discussed separately on the ecologic relationship of this plant and also of two others, water hyacinth and alga, with the anopheline incidence of an area.

PISTIA.—A question was raised that *Pistia stratiotes* must invariably be associated with *philippinensis* breeding and a suggestion came that scrupulous cleaning of *Pistia* alone from watery areas would remove the vector species and malaria altogether.[29] We have seen before that quite a large number of species finds the plant a suitable associate and *Pistia* cannot claim to have such exclusive association with *philippinensis* alone. If any species could lay a claim on such an intimate association, it is the *A. ramsayi*. The *Pistia-philippinensis* bogey is founded on the belief that *Anopheles* requires more calcium which *Pistia* provides in the shape of calcium sulphate needles. These when ingested perforate the stomach wall of the larvae, and further, these perforations to help mechanical transference of the malaria parasites to the salivary glands through body cavity are retained in the adult stomach.[5] The idea is fantastic, for the digestive system of a larva is profoundly changed before it is transformed into the adult and undergoes complicated processes of histolysis and histogenesis. Furthermore, the perforations have no place in the completion of the life-history of the malaria parasites. Neither is the calcium requirement of *Anopheles* substantiated by facts. The calcium content of *Culex* mosquitoes reared from non-*Pistia* water on analysis was found to be of a much higher order than that of *Anopheles* from *Pistia* water.

Field experiments to remove *Pistia* in certain rural areas of the older alluvial zone of Bengal and of lateritic area were taken up to study the effect. This removal was not sufficient to eliminate the breeding of the vector species or of malaria in the environs.[56] Removal of *Pistia* has as much importance as clearance of aquatic vegetation has, as a general anti-larval measure : it is just a synchronism of vegetation clearance.

WATER HYACINTH.—Water hyacinth, *Eichornia speciosa*, has been found inhibitory to the breeding of *philippinensis* and *sundaicus* in Bengal when the water courses are densely covered by the plant. The absence of these two species in such situations does not so much depend on mechanical obstruction to oviposition or to respiratory difficulty of the larvae but to cutting off of sunlight by the plants and consequent destruction of the algae (*Enteromorpha*) and other appropriate vegetation (*Hydrilla*) so important for the growth of their larvae. This fact has led to the ill-conceived idea of utilising a thick coverage of this plant to control the breeding of the two species.[15] Almost the same effect can be obtained with any other plant when thickly grown on any water surface and the principle underlying this measure agrees in effect with the too well-known method of herbage packing in controlling anophelines.

Later work has failed to substantiate this method of water hyacinth coverage to control *sundaicus* in Orissa coast[23] and it appears that this is likely to cause more harm than good. A thick growth of the plant tells adversely on the composition of the water underneath making it extremely foul after sometime. If the plant is encouraged it not only would lead to domestic water difficulty in rural areas and an impediment to the growth of fish and blockage of navigation, but would actually induce more breeding of other mosquitoes particularly *aconitus* which finds the plant admirable for its development as already stated ; besides this would introduce the ever-increasing culicine menace. The idea of introducing water hyacinth to control anopheline breeding should therefore be discouraged.

ALGAE.—Importance of green algae and diatoms in the production of anophelines has long been recognised.[51] *Spirogyra* has a close association with *philippinensis* in Bengal as mentioned before, *subpictus* is equally involved.[45] Algae form the chief source of nutrition to the larvae and it has often been noticed that their removal automatically controls breeding. A close association of *sundaicus* with the floating algae *Enteromorpha, Oscillatoria, Oedogonium,* and *Lyngbya* has been observed ; in the absence of these algae the growth of *sundaicus* larvae is impeded.[42] The algae also help to protect the larvae from their predators.

The algae particularly the minute forms belonging to Volvocaceae and Pleurococcaceae are responsible for the breeding of anophelines in another way ; they generate enormous quantity of oxygen during the day-time as a result of photosynthesis.[11] This is very essential to aid respiration in clean water breeding anophelines. On the other hand, thick growth of *Microcystis* and a few other blue-green algae inhibits the breeding of anophelines.

VII. RICEFIELD BREEDING

The intensity of anopheline breeding in ricefields of Bengal varies in different localities within certain limits. Almost all the common species 11 or 12 in number including *philippinensis* may breed in these fields, but the breeding here is not always greater than in other types of water collections inside the villages ; it may be so in a few instances of course. With regard to *philippinensis* rice fields play a very minor rôle : most fields do not show the breeding and even if it is present, the incidence does not exceed 0·3 in 10 standardised samples against 10·6 in village ponds. In other words, the breeding of the species in ponds is over 35 times as great as that in rice fields.[47] *A. culicifacies* and *minimus* where they prevail are also not usually detected breeding in the ricefields, nor is *sundaicus* a problem of ricefields in the estuarine zone.[53] Ricefields therefore are not considered a danger malariogenically in Bengal.

A. hyrcanus the innocuous species constituting nearly 50 per cent of the total collection from ricefields at any time forms the bulk of the breeding. The maximum infestation of these fields occurs in September when *varuna* also has its peak prevalence. *A. annularis* breeds more intensively in stagnating water towards the end of rice season in January.

Rice plants 1′ to 2′ in height provide the best range for the development of most species. *A. philippinensis, pallidus* and *varuna,* three important species, seem to prefer breeding in fields with plants usually between 15″ and 18″ in height affording some shade. Beyond this height the anophelines become rare excepting *pallidus* which may breed until the plants reach a height of 2′6″.[47] The rice plants exert in two ways on the life of anophelines ; (1) by influencing the water temperature which in open spaces sometimes reaches 42°C or above in the afternoon, and (2) by regulating the growth of plankton specially algae like *Spirogyra* which is reduced in shade. More will be found on the effect of these two factors dealt separately under appropriate sections.

VIII. Biotic Factors

The larval incidence of a place is kept under check by a host of predatory insects, particularly Hemiptera and Coleoptera living in water ; the surface minnows also are considered as important in this respect. Dytiscidae, both larvae and adults, attack mosquito larvae. *Dytiscus* larvae are extremely voracious ; they pierce the skin of *Anopheles* larvae and suck the fluid by means of their long sickle-shaped and hollow mandibles which are pointed and perforated at tip. *Hydrophilus* larvae are even more voracious. They seize their prey and completely eat them up.[20]

Among Hemiptera, *Ranatra longipes* catches *Anopheles* larvae by pincer-like front legs and passes it to the rostrum and the feeding is completed in 8 to 15 minutes. *Sphaerodema annulatum* (Belostomidae) and certain Hydrometra are proved enemies of mosquito larvae. The bug, *Sphaerodema,* kills mosquito larvae by sucking their blood with the fine mouth-parts. A bug swimming about with a larva at the tip of the rostrum is quite a common sight if the two are kept together in a jar. After the body juice has been sucked the larva dead and empty is dropped to the bottom. Sometimes the whole body is reduced to fragments. It takes 6 to 8 minutes to suck a larva completely and then the empty skin is pushed out by the front legs of the bug.[48] Odonata nymphs are predatory but they mainly browse at the bottom and may not be so harmful to *Anopheles* larvae.

A few Molluscs may be of some use in making the water unsuitable for the growth of *Anopheles* larvae by emitting certain secretion from their body. *Rana tigerina* has also been reported as feeding on mosquito larvae.

Food contents in the stomach of four common fish in Bengal, *Aplocheilus* (=*Panchax*) *panchax, Barbus stigma, Esomus danricus* and *Colisa* (=*Trichogaster*) *fasciata* were analysed in their natural environment in order to find out how far they are responsible in the destruction of mosquito larvae.[40] *Barbus* and *Esomus* proved to be essentially vegetable feeders ; as such they do not seem to have any direct check on the larval population. *Barbus,* however, as in Java, may by its feeding on algae which provide sustenance to a number of anopheline species bring about a reduction of their numbers indirectly. *Colisa* may feed on insects but it is not a surface-feeder and naturally would not have much influence on the anopheline larvae. Only *panchax* showed some evidence of feeding on *Anopheles* larvae and eggs. Roughly 10 per cent of the *panchax* examined were found to have fed on anophelines.[40] Evidence however lacks to prove that this fish has a specific attraction for these larvae, but it seems to relish any food whether of vegetable or of animal origin. The cosmopolitan feeding habit of the fish finds support in the recovery of juvenile forms of *Vivipara bengalensis* from their stomach.

Microsporidia among protozoal parasites are known to cause a heavy mortality in anopheline larvae particularly during monsoon period. The genus *Thelohania* ranks highest in this respect. In Bengal we have been able to distinguish four of these, *Thelohania obscura, T. legeri, T. indica* and *T. anomala* as infesting larvae of *subpictus, vagus, ramsayi, annularis, hyrcanus, varuna* and *barbirostris*.[46] These parasites may be seen throughout the year but are more prevalent during April to September. Infected larvae look opaque in the thorax and abdomen in an advanced stage of infection and they become sluggish and eventually die within 2 to 6 days. Besides *Thelohania,* two other genera *Nosema* and *Plistophora* have also been recorded as parasitising mosquito larvae.[10]

Nematode worms of the genus *Mermis* are also known to parasitise both the larvae and adults of *Anopheles.* The infestation by these worms is also common during the monsoon months, August and September, in Bengal. The worms live in the haemocoele of the host insects and seven species, *hyrcanus, barbirostris, varuna, ramsayi, annularis, philippinensis* and *tessellatus* are known as vulnerable in the larval stage. Larvae infested by these worms which are 5 mm. to 8 mm. long do not appear to suffer considerably as they undergo the moults quite normally up to the last larval stage, but no further, when the worms emerge by killing the larvae.[10] Only one worm emerges from a host larva. The worm that attacks adult *Anopheles* is much longer and measures 14 mm. to 17 mm.; here also with the emergence of the worm the host is killed. Adults of *annularis* and *subpictus* are known to be attacked thus.

Several *Anopheles* both larvae and adults are susceptible to attacks by two species of *Coelomomyces, C. indiana* and *C. anophelesica.* A heavily infested larva is filled with numerous yellowish sporangia destroying the fat body, and its imaginal buds are suppressed. The larva is killed before pupation.[10]

IX. PHYSICAL FACTORS

TEMPERATURE.—Restricting effect of water temperature on the life of anopheline larvae particularly of *minimus* in the ricefields of Assam has already been studied. The restricted breeding of *philippinensis* also in Bengal fields appears to depend on this factor to a great extent. Towards the beginning of cultivation when shade is not sufficiently formed the temperature of the water in a ricefield often reaches 42°C or above towards the afternoon (3 P.M.) on clear days and is beyond the tolerance limit of the species mentioned. At such high temperatures (43°C or 44°C) species like *hyrcanus* and *vagus* can only survive. In Assam two more species *barbirostris* and *culicifacies* have also been found to survive this extreme temperature.[60] *A. subpictus* breeds freely at 32°C to 34°C,[21] and so do many other species.

There is a general agreement that *philippinensis* does not breed in shallow pools fully exposed to the sun or in absence of aquatic vegetation. This in fact supports the contention that water temperature which greatly rises under such conditions is a great limiting factor. The apparent discrepancy in the findings of other workers who consider that cutting off of sunshine is inhibitory to the breeding of the species melts away when we remember that their observations were based on deep water breeding where in the presence of submerged vegetation the sun is incapable of raising the temperature to the critical level. On the other hand, this favours the growth of plankton which in turn provides the sustenance to the species.

SHADE.—The shade affects larval growth in two ways: it helps decomposition of the vegetation growing underneath for want of sunshine and it prevents oviposition of females which often find the overhanging plants affording the shade an obstacle to reach water as proved for ***minimus*** in Assam streams[59] and for *culicifacies* in South Indian ricefields.[33] In partial shade the plankton particularly microscopic algae and diatoms may grow to provide food, but the water temperature which is raised to the critical level through the free play of sun's rays inhibits the growth of the larvae, whereas in dense shade although the water may remain cool enough the nutritive factor in the form of plankton becomes scarce for want of sunlight.

SILT.—The silt appears to be one of the limiting factors in deciding the breeding of anophelines in an area despite the finding in Assam that this has no lethal or larvicidal effect on *minimus* larvae.[61] Introduction of silt-laden flood water has produced effective result in controlling anopheline breeding although certain workers seem to think that the true cause for this inhibition of breeding does not lie so much in the silt as in the current that brings it. We have however pretty often seen that in rainfed ricefields where current is absent most species excepting the cosmopolitan *subpictus* and *vagus* would not breed after puddling which makes the water go turbid. But soon after the silt in the fields is deposited and the water becomes clearer other species like *hyrcanus* and *annularis* appear. Introduction of silt water from tidal rivers at high tides has always proved highly effective in the estuarine zone of Bengal in controlling the breeding of *sundaicus* in the borrow-pits along railway embankments, and so long as the silt remains the breeding is not resumed. Similarly in the deltaic zones the breeding of *philippinensis* in several ponds has been subdued by feeding them with flood water from the neighbouring irrigation channels.

WATER TABLE.—In Bengal it has long been recognised that in low-lying deltaic tracts a superabundance of surface water far from being harmful may exert a beneficial influence by covering the ground with a protective sheet of water.[2] This is explained by the fact that in heavy rains or in inundations the breeding places of anophelines are washed out and the aquatic stages of the mosquitoes do not get a chance to develop. This fact in essence led to the enunciation of the view that by raising the water table in an area with low subsoil water level the breeding of the vectorial species and consequently malaria may be wiped out in deltaic Bengal.[13] The soaking or submersion of soil in many instances is only relatively beneficial, and its real value must necessarily lie on the actual reduction which this measure brings about in the breeding of the vectorial species and on nothing else. It is certainly risky to assume that all watery areas thus introduced if allowed to continue long should always remain immune.

With respect to subsoil water table the different vector species exhibit a great tolerance and the same *Anopheles* can breed in such a wide range that a raising of the table in the normal way by irrigating the fields or by any other means is not likely to alter the breeding propensity very materially of the species. In the submontane zone for instance, the chief vector *minimus* breeds in areas in Teesta valley with the average subsoil water level at 16′3″ below the ground during dry months, whereas in the terai near Siliguri with the same species breeding profusely this level is only 6′ 9″ at the corresponding period. In the undulating deltaic areas to the west of the State where *philippinensis* and *culicifacies* are the predominating species the average subsoil water level varies from 18′ 1″ to 6′ 1″ and 39′ 1″ to 14′ 6″ in the wet and dry weather respectively in normal years. In Bengal plains, lower down the delta, where *sundaicus* appears to be the chief vector the subsoil water level varies from 4′ 7″ to 6′ 2″ in the different seasons,[57] and at the maximum level recorded here, we have already seen, both *philippinensis* and *minimus* in their respective zones would also breed.

The range of subsoil water level within which a species would breed is therefore so flexible that the idea of obliterating a species by the mere raising of this level, as advocated in certain quarters, seems highly inoperative. Water columns have been found to vary not only in the different topographical regions discussed here, but also within the same zone from place to place depending on the proximity to rivers and on the amount of rainfall.

The anopheline breeding in general at different depths of surface water shows that this is usually restricted to the depths from ½″ to 3′. But more frequently, provided there are no other detrimental factors, most clean water species, particularly *philippinensis* and *pallidus*, prefer to breed in water columns varying from 2″ to 1′ and anopheline incidence within this range is distinctly higher, almost double of that seen in any other column beyond this range at either end. A *vagus* has also been known to avoid a water column above 1′ in depth.[47] Apparently a very great depth of water is not liked by the anophelines, evidently for reasons of scarcity of supporting vegetation away from the water edges and owing possibly to the abundance of their natural enemies in deeper water or to other adverse factors like wave action.

X. CHEMICAL FACTORS

CHLORIDES.—Salinity plays a great rôle in the life of anophelines. It has already been pointed out that for *sundaicus* breeding a certain amount of salt concentration is essential and the best range appears to lie between 94 and 188 parts per 100,000 from samples of water round about Calcutta, and lower down the estuary the tolerance is higher reaching about 600 and above. The factor thus is highly variable with *sundaicus*, which at the other extreme would even breed in water with the chloride content as low as 16 parts per 100,000.[42] Whether the species breeding at such lower ranges can retain its vectorial status is however doubtful. Data collected from samples of water taken in course of actual breeding of *sundaicus*, and also before and after this, showed that the salt concentrations were regularly at a higher level during the breeding than when it was not.[49]

Within the range of tolerance exhibited by *sundaicus*, more usually towards the bottom, species like *subpictus*, *vagus* and *annularis* in the descending order may also prevail, whereas the factor has proved inimical to the growth of *philippinensis* mosquito. It stops breeding with the slightest rise in the chloride content in the normal habitat, particularly ricefields.[35]

HYDROGEN ION CONCENTRATION.—Hydrogen ion concentration indicates the favourable or unfavourable association of chemical and biological factors in the breeding places of anophelines and is no more than an indicator.[52] The pH value of waters providing the best breeding facility to a large number of anophelines appears to lie between 7·2 and 8·5. Only exception has been *minimus* which breeds in water below this range at pH 6·5 to 7·5. This indicates that the anophelines are mostly alkaliphile and avoid acid waters.

A. philippinensis finds a pH range of 7 to 7·5 most suitable in the districts of Bengal, and 7·4 proved the optimum for *subpictus* larvae.[21] In a series of observations the average pH came to about 8 or 8·2 for *sundaicus*[48] which seems to possess the highest tolerance to this factor.

The pH value over 8 indicates that the sample does not contain free carbonic acid but carbonates with or without bicarbonates. A value above 9 or below 5·5 seems detrimental to the growth of *subpictus* larvae[21] and perhaps of other allied species in the plains showing that extremes of both acidity and alkalinity are inhibitory to anopheline breeding.

CARBONATES.—Analysis of carbonates in the natural breeding waters failed to produce any evidence of the existence of a direct relationship between this factor and anopheline breeding. The carbonates detected did not show either any correlation with the pH factor, as it ought to show, since pH is closely interlinked with the presence or absence of carbonates in water. Further work is expected to throw more light on this point. The average reading for carbonates in the breeding places round about Calcutta particularly of *sundaicus* came to 13·4 ; the lowest detected was 4·2 and the highest 19·2. The figures only indicate, as in pH, that the anophelines of the delta are alkaliphile ; but there was nothing in the data obtained to suggest that the factor may be utilised in the determination of the specific nature of breeding in a place.

ALBUMINOID AMMONIA.—A large number of water samples from breeding places of areas in the suburbs of Calcutta was examined to find out the relationship of this factor with the prevalence of anophelines particularly *sundaicus,* the vector in the zone. On analysis it was found that a correlation exists between this constituent and the breeding of *sundaicus.* The species has always been detected when the albuminoid ammonia content of the breeding water was low compared to the figures obtained both before and after the breeding. The amount required was indeed very small and ranged from 0·006 to 0·04 part per 100,000.[49] With the lowering of albuminoid ammonia, free ammonia was found to increase and *vice versa.* Free ammonia was also present in traces usually in quantities below 0·01 part per 100,000, in a static water breeding mostly *subpictus* and *sundaicus.* Others like *culicifacies* avoid highly ammoniacal water[19] and are partial to organic pollution, so are *stephensi* and *varuna.*

DISSOLVED OXYGEN.—Investigations into the relationship of dissolved oxygen content with anopheline breeding in the ponds, tanks and ditches of Bengal proved that this factor though important has no absolute bearing on the breeding of the various species within the limitations normally present in such environments. The species *barbirostris, subpictus* and *varuna* have shown a tolerance for the oxygen concentration varying from almost 0 to 7 mg. per litre[11] in accordance with the varying breeding places when taken in the morning hours between 8 and 10. They are very little affected by the wide fluctuation in this factor in their habitat.

Somewhat different is the position with *annularis* which has a tendency to rise in frequency with a rise in the oxygen concentration until the peak is reached at 3 to 4 mg. ; after this the species declines again in density. *A. hyrcanus* and *ramsayi,* on the other hand, show a reverse effect ; their density which is highest at concentration of 1 mg. and below falls with the increasing concentration of oxygen in water.[11]

Oxygen toleration limits of different species discussed above lose their significance as a practical measure-stick when we consider that the content in a static breeding place in rural areas shows great diurnal fluctuation. This content in the same breeding area may rise from a low to the high value in course of the day depending on the sun ; the minimum concentration is reached at 6 in the morning and maximum at about 2 to 3 in the afternoon. With the cooling of water towards the evening and at night-fall the content falls again. But all these changes in the oxygen content of the breeding place do not cause any visible discomfort to the larvae; nor do they bring about a corresponding fluctuation in the larval incidence.

Despite the doubts raised in placing much reliance on this factor, some workers[6] consider that high dissolved oxygen content is a significant factor in the breeding of anophelines in a natural water. More work is desired to settle this point.

Finally, in the compilation of an account like this a good deal of foraging into others' works is imperative and it is possible that I might have omitted some; for this which is not purposive I crave indulgence. Ecologists will perhaps find here a mere attempt to consolidate from fragments the existing knowledge of a group of insects which has been in the mind of mankind from the dawn of civilisation. No one is more conscious than myself that in this attempt there have been many a lapse, but if ecology means the study of relationship of organisms with their environment involving both intensive and extensive field observations on the natural history, we are no doubt trodding on the right path. The problems of ecology are diverse and the inroads to their solution are many. It has only been possible here to deal with a few important aspects of the innumerable problems of mosquito ecology, and if I have failed to give a more comprehensive picture, I expect at least adequate attention should now be focussed on the riddles and lacunae that await vigorous pursuing in this country. India as a tropical country with her varied animal life, no doubt, offers a much wider scope than most countries for the study of ecology and yet this fascinating subject has not advanced to the extent it has in Europe and America. Ecological studies imply not only spending long hours in the field facing the rigors of outdoor life, but often a close follow up in the laboratories as well for confirmatory tests. Obviously, one cannot be blamed for avoiding such hobbling pursuits, and maybe that has been the cause for the lack of buoyancy which is so much needed for such work. Science must progress, no matter howsoever the approach may be, smooth or ragged; dauntless she goes in her forward march. Let us hope that realisation will dawn on us and the strive for knowledge and the spirit of achievement in the realm of animal ecology may not sag in us. Ample reward awaits those who would venture to dive deep and let me conclude with a plea for better and more active participation by our scientific workers in this discipline of zoology.

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SECTION OF ANTHROPOLOGY AND ARCHAEOLOGY

President:—DR. B. K. CHATTERJEE, M.Sc. (Cal.), D.Sc. (State) Paris

PRESIDENTIAL ADDRESS

RACIAL COMPONENTS OF THE TRIBAL POPULATION OF INDIA

It is my foremost duty to offer you my sincerest gratitude for the honour you have conferred on me by electing me to preside over the deliberations of the Anthropology and the Archaeology Section of the Indian Science Congress Association. I am fully conscious of my limitations, but I earnestly hope that I will get your full co-operation in course of our deliberations.

Before I proceed to discuss some problems of Indian Anthropology I would like to state briefly the general distribution of the tribes in India and also their linguistic and racial compositions.

In India, there are numerous tribes possessing different physical characters, cultures, languages and modes of life. The total number of the tribal population in India (according to Census of India 1951) is about 19,116,498 distributed over five Zones, *viz.*, Himalayan--Eastern, Central-Southern, Central-Northern and Southern and Western Zones. It may not be out of place to mention here some of the important tribes of the zones mentioned above.

1. In the Himalayan-Eastern zone, we find the following tribes:
   (*a*) Garo, (*b*) Khasi, (*c*) Naga, (*d*) Abor, (*e*) Dafla, (*f*) Tagin, (*g*) Galong, *etc.*
2. In the Central-Southern zone,
   (*a*) Gadba, (*b*) Parja, (*c*) Gond, (*d*) Kol, (*e*) Pardhan, *etc.*
3. In the Central-Northern zone,
   (*a*) Kisan, (*b*) Lohara, (*c*) Malpaharia, (*d*) Munda, (*c*) Santal, *etc.*
4. In Southern zone,
   (*a*) Chenchu, (*b*) Kadar, (*c*) Kanikkar, (*d*) Muthuvan, (*e*) Palliyan, (*f*) Urali, (*g*) Kuravan, *etc.*
5. In Western zone, we find the following tribes:
   (*a*) Bhil, (*b*) Dhulia, (*c*) Dubla, (*d*) Gamta or Gamit, (*e*) Varli, (*f*) Nayak, *etc.*

LANGUAGES SPOKEN

There are about 30 different groups of spoken languages and each group consists of one to five or more different dialects. About half a dozen of these belong to the family of languages known as Austric which is very widely distributed and might be the earliest family of languages spoken in India. Since the Indo-Austric speeches are divided into two sub-groups, Kolarian or Munda and Khasi, some are of the opinion that there had been two routes of migration, one from the West and the other from the East of the Himalayas. In the former case the languages are now known as Munda or Kolarian spoken in Central India, and the latter is termed as Monkhmer, spoken by the Khasis of Assam. It should be remarked that the Nicobarese of the Nicobar Islands also speak a language which bears affinities with the Eastern branch.

The Sino-Tibetan languages also fall under two groups, Tibeto-Burman and Sino-Burmese, the Himalayan and the North Assam tribes speak the former, the Kachin and Kuki-chin tribes belong to the latter sub-group and the Naga speeches belong to an intermediate position. Though the Kuki-chins are Indian tribes, they are racially and culturally more linked with the people of Indian Archiplego and the tribes of the Pacific Islands. Dravidian languages are spoken not only in South of Godabari but also among the Brahui in the isolated places of North West and Maltos in the Rajmahal Hills.

The European languages subsequently infiltrated into India due to invasions on a small or large scale, between 1500 B.C. and the beginning of Christian Era. It would appear from the historical records that the Persians and Greeks and after them the Sakas or Scythians and the Kushans came from Central Asia and later on, about 5th century A.D., another horde of people known as the Huns invaded North India from Central Asia. About 8th century, the Muslims appeared and continued their inroads until the establishment of the Mughal Empire in India in the 16th century A.D. By that time the Portuguese had already settled in Goa.

DIFFERENT THEORIES REGARDING THE RACIAL ORIGIN OF THE PEOPLE OF INDIA

In the opinion of some anthropologists the oldest stratum of India's population is Austro-Asiatic, or Proto-Australoid in origin. These people are long headed, dark skinned and broad nosed. Their physical features are still to be found among the tribal population of Chotanagpur and Central India. According to Hutton, these proto-Australoids came to India from the East. The people had long head and were matrilineal in descent. Apart from these, a round headed Armenoids had also penetrated into India from the Asia-minor, Mesopotemia, *etc.*, *via* Persia. The people in the Himalayan-eastern Zone are Mongoloid either of the tall Tibetan type or of the shorter and darker Burmese type. According to Buxton some of Risley's Mongolo-Dravidian groups are the variations of the Parrorean race which was termed by Haddon.

Sir Arthur Keith on examining the Bayana skull opined that although the distinct age of the skull was uncertain, still it appeared to be of considerable antiquity as judged by the degree of mineralization. The cranial shape is long and disclosed undoubtedly Mediterranean affinities with which others do not agree. Other accounts on pre-historic skulls are given by Sewell and Guha particularly on the skulls excavated at Nal and Mohenjodaro. Having examined these skulls, Sewell and Guha and later Guha and Basu pointed out that during the Chalcolithic period in Indus Valley and in Beluchistan, it appeared that the racial types were similar to those excavated at Kish and Al'ubaid in presargonic Sumaria and consisted of Mediterranean strain. They are long headed types probably of proto-nordic affiliation along with plano-occipital broad headed race which is the characteristic feature of the people of Asia-minor at the present time. Elliot Smith on examining the Adittanalur skulls, excavated by Rea in 1901, fuller details of which were published by Zuckerman, stated that the Australoid character of one of the skulls was confirmed. Turner and Basu examined certain modern skulls of Central India and Chotanagpur and noticed the presence of Australoid character in some of them.

On the basis of certain somatometric data, Risley propounded a theory and classified the people of India as follows:

1. Turko-Iranian type represented by Baloch, Brahui and Afghans of Chitral and North Western Frontier Provinces which are now in Pakistan.
2. The Indo-Aryan type occupying the Punjab, Rajputana and Kashmir having its members, the Rajputs, the Khatris and the Jats.
3. The Scytho-Dravidian type of West India, comprising the Maharastrian Brahmins, the Kumbis and the Kurgs probably formed from a mixture of Scythian and Dravidian elements. The former element predominated in the higher groups while the latter one predominates in the lower.
4. The Aryo-Dravidian type to be found in Uttar Pradesh, in some parts of Rajputana, in Bihar and in Ceylon and also present among the high caste Brahmins, as well as among the low caste people, viz., the Chamar.
5. The Mongolo-Dravidian type of lower Bengal and Orissa found particularly among the Bengalee Brahmins and Kayasthas, having a strain of Indo-Aryan blood in the higher group.
6. The Mongoloid type of the Himalayas, Nepal, Assam and Burma represented by the Kanets of Lahul, Kulu and the Lepchas of Darjeeling, the Limbus and the Gurungs of Nepal and the Bodo of Assam.
7. The Dravidian type extending from the valley of the Ganges down upto the whole of Madras, Hyderabad, Central Provinces and Chotanagpur.

Sir William Crooke and Thurston following Risley's lead worked among certain people and on certain glocceries of tribes and castes living in the United Provinces and in Southern India, respectively.

Von Eickstedt attempted to reconstruct the racial history of India as a whole and found that Veddid of the primitive jungle folk, *viz.*, Gondid or dark brown wavy hair race, Malid or black brown progressive people of Southern planes who are again made up of, Southern or Tamilid and Northern Deccanid or Kolid races, and lastly the progressive new India or Indid group divided into (*a*) brown and (*b*) graceful and coarse light brown, North India types. Of these, the Melanid race is the oldest and the descendent of the Indo-Negroid or Eastern branch of the group of Negro races. It may now be described as belonging to the frinze of the Negroid and Europid races.

A different racial reconstruction was attempted by Guha on the basis of his original somatometric data taken on different tribes and castes of India. Guha opined that there was a short dolichocephalic strain with high headed and moderately broad nose, over which was superimposed a brachycephalic race of mostly plano-occipital type in Western and Eastern India, and a proto-Nordic type in North Western India. In addition, the tribal group definitely revealed a Negrito strain now mostly submerged in the proto-Australoid element, which in combination with various other strains made up the aboriginal population of this main land, *i.e.*, excepting those who are living in the sub-Himalayan regions and Hills of Assam, where the Mongoloids, both long headed and broad headed tribes, form the chief constitutent of the population.

According to Guha racial elements came from six main racial types having 9 sub-types which are as follows:

(1) The Negrito, (2) The Proto-Australoid (3) Mongoloid consisting of Palae-Mongoloid of long headed and broad headed types and the Tibeto-

Mongoloids ; (4) the Mediterraneans comprising of Palae-Mediterranean, Mediterranean and the so-called oriental types ; (5) the Western Brachicephal consisting of the Alpinoid, the Dinaric, the Armenoid and lastly (6) the Nordic type.

SEROLOGICAL STUDY

As regards the Serological study, L and H. Hirschfald were the first biologists to study the Indian blood groups. They examined blood samples of 1000 Indian soldiers in Macedonia during the first World War and found that the high percentage of group B exists among them. Unfortunately, the sample examined by them was a Hetorogeneous one composed of Gurkhas, Gharowals, Jats and Rajputs. Then we find Malan, and Lahiri also carried on serological tests among the Rajputs and mixed Hindus from the United Provinces, from the Dravidian people, and Tea garden labourers of Chotanagpur belonging to different castes and tribes, all lumped together. McFarlane, Sarkar, Aiyappan, Majumdar and others also surveyed blood groups of different tribes and castes of India. The result of these reports regarding the blood groups in India does not warrant us to draw any far reaching conclusion, since the materials on the ethnically separated groups of this country are not sufficient.

Blood grouping tests have been done mainly in ABO system but no reliable worker has yet completed the test in M., N., system. As far as Rh system is concerned, Khanolkar and Sanghvi have tested and carried out the Rh tests in a few Hindus, Parsis and the native Christians. But all the Hindus were Rh positive. It is not known whether the Rh positive belong to Rh^{O}, Rh^{1} or Rh^{2}. It is difficult to judge the affinities of the Indians to the white, the Negroid or the Mongoloid races.

On the basis of the somatometric data collected by me particularly on the Kols of Central Provinces, Santals of Santal Parganas and the Kanikkars, the Uralis, the Muthuvans, the Malapantarams, the Kuruvans, the Paliyans and the Mannans of Travancore-Cochin and the systematic analysis and comparison of those data, the following results were arrived at.

THE KOL OF MADHYA PRADESH

The following account is based on the somatometric measurements and observations made by me on 127 adult male and 24 female Kols of Central Province and on adult males of the following tribes, *viz.,* the Urali, the Malapantaram, the Paliyan, the Kuruvan, the Muthuvan, the Kanikkar and the Mannan of Travancore and Cochin State, apart from the somatometric study of the Santal of Santal Parganas. Out of these tribes, I would like to deal with the Kol of Central Province in detail.

The techniques advocated by Manoco, 1906 and the Geneva 1912 and the subsequent modifications were followed in taking somatometric measurement. All the measurements are given in millemeters and were taken by the instrument manufactured by Messrs. Herman Rickenbach and Co., at Zurich.

Dalton[1] records a tradition connecting the Kols with the Cheros, who prior to the Aryan occupation of the Gangetic Provinces were the dominant race in Gorakhpur, Behar and Shahabad and surmised that the now despised Kol was in those days the language of that part of India.

The modern province of Behar anciently known as Magadha, has numerous antiquities attributed to the Cheros and Kols, and from the legends handed down, it appears that the sovereigns of the country at one time was the Cheros, the people in most of these parts being the Kols.

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[1] Dalton, E. T.—Descriptive Ethnology of Bengal, p. 151, Calcutta, 1872.

Kabar, the most important of the ruins attributed to the Cheros or Kols was evidently the work of a powerful ruler and probably the stronghold of the princes of the race. These legends of the Kols are still preserved in Behar. Dalton[2] further connects the Nagbangsis of Gorakhpur who now consider themselves as Rajputs and acknowledge the Raja of Chotanagpur as the head of the family, with the Kols. Russel[3] and Hira Lall observe that the Santals are a branch of the Kols, who have broken off from the parent stock and have been given a separate designation by the Hindus. The word Kol is probably the Santali "Har", a man, and the word is used in various forms such as Har, Hero[4], Ho, Koro, by most Munda tribes in order to denote themselves. Russell and Hira Lall[5] further added that the Mundas, the oldest known inhabitants of India, perhaps came originally from the South East, the Island of the Indian Archipelago and the Malay Peninsula, unless India had been their original home and those countries were colonised from it. Whether autocthones or immigrants, the Kols comprise one of the best known and most important aboriginal tribes, generally designated in the Sanskrit Texts as Nisada. In the Vishnu Purana (1, 13) the Nisada is described as of the complexion of a charred stake with flattened feature and dwarfish stature. The Bhagavata Purana (IV, 14, 44) describes the Nisada as black like crow, very low statured, short armed, having high cheek bones, low-topped nose, red eyes and copper coloured hair. In the Padma Purana (II, 27, 42-43) it is said "His (Nisada's) descendants are settled in the hills and forests, the Nisadas, Kiratas, Bhilla, Nahalakas, Bhramaras, Pulindos and other *Mleccha* tribes addicted to vices, are all sprung from his body," Chanda[6] who collected these references concluded that the epic and Puranic legends evidently contain genuine traditions relating to the physical characteristics of the aborigines, whom the Vedic Aryans met in the plains of Northern India. The Nisadas were too numerous to be annihilated and too powerful to be enslaved or expelled *en masse*. The barbarians of the Vindya hills belonging to the Nisada stocks according to the Puranas, are called Sabaras, Pulindas and Kiratas.

The modern representatives of the Nisadas speak dialects belonging to three different linguistic families. The Bhila mostly speak an Indo-Aryan language, while the Gonds, the Khonds, the Oraons and the jungle tribes of Southern India speak Dravidian languages ; and the jungle tribes of Chotanagpur and the Savaras and Juangs of Orissa speak languages of the Munda family. The Kol,[7] the Baigas and other Munda tribes have given up their ancient languages in favour of the local Indo-Aryan speeches.

Chanda was inclined to the view that Munda (Austro-Asiatic) was originally spoken by the Nisada race as a whole and Indo-Aryan and Dravidian dialects have been adopted by some Nisada tribes as a result of their contact with their more civilised neighbours. This view is contested by Heiné-Gildern who appears to associate the Mongoloid Groups, *viz.*, the Khasi, the Riang, the Palalung, the Monkhmer and the Annamites with the Austro-Asiatic speech while about the Mundas, he was doubtful of their racial purity, having been subjected to numerous influences. Professor Przyluski goes a step further and presume that the Kols and the Mundas with brighter complexion were superimposed on a dark complexion race which he designated as Proto-Dravidian. In some cases those two ethnic elements lived together in the same territory having an aristocratic bright complexion (probably yellowish) as well as body of plebians with a dark complexion. The social organization of the Kol of the present day does not preserve this racial dichotomy, if it had ever existed.

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[2] Dalton, op. cit., p. 162.

[3] Russel, R. V. and Lall Hira—Tribes and Castes of the Central Provinces of India, Vol. III, pp. 501-503, 1916.

[4] Risley, H. H.—Tribes and Castes of Bengal, p. 505, Vol. I, 1891.

[5] Russel and Lall Hira—op. cit., pp. 501-503.

[6] Chanda, R. P.—The Indo-Aryan Races, pt. I, p. 5, 1916.

[7] Census of India, 1931, Vol. XX, Central India Agency, Pt. I, Report, 179, 1933.

At the present moment the Kols are to be found scattered in Central India and the United Provinces particularly in the area bounded by a portion of the rivers Chambal and the Ganges in the North, and the Chitor Hills in the West and the Nurbudda river and the Mohadeo hills in the South ; but a high concentration of these people is to be found inhabitants of the Rewa and the Jabbulpur areas and were of "Rautia" and Thakuria Gotas, *i.e.*, sub-castes.

Table 1 shows the mean values with their probable errors of different measurements, the standard deviation, the coefficient of variation, the maximum and the minimum of the male Kol.

TABLE 1.

Kol Male	Mean with probable error.	Max.	Min.	Strand. Deviatn.	Coeff. of Varian.	Sex Ratio	Mean Deviatn.
Stature ...	1608·8 ±4·61	1737	1492	51·98	3·23	1·07	...
Max. Hd. Length.	183·1 ±0·53	198	170	6·07	3·31	1·04	4·86
Max. Hd. Breadth.	138·0 ±0·41	151	128	4·63	3·35	1·03	3·51
Auric. Ht. ...	130·2 ±0·67	149	107	7·65	5·87	1·02	5·95
Sup. Fac. Ht. ...	58·1 ±0·39	71	43	4·45	7·65	1·05	3·50
Total Fac. Ht. ...	113·8 ±0·65	133	92	7·36	6·45	1·07	6·05
Nasal Ht. ...	47·6 ±0·33	57	36	3·77	7·92	1·06	2 82
Nasal Br. ...	37·2 ±0·23	43	31	2·59	6·96	1·10	2·14
Nasal Depth ...	17·0 ±0·18	21	9	2·04	1·20	1·09	1·40
Min. Front. Br.	102·3 ±0·28	111	90	3·19	3·11	1·03	3·14
Max. Bizy. Br. ...	131·2 ±0·35	139	121	3·98	3·03	1·05	3·34
Big. Br. ...	98·9 ±0·41	111	87	4·62	4·67	1·03	3·67
Int. Orb. Br. ...	29·2 ±0·27	51	24	3·05	1·04	1·00	2·06
Orb. Nas. Br. ...	101·8 ±0·38	114	94	4·31	4·23	1·02	3·50
Orb. Nas. Arc. ...	117·2 ±0·41	135	105	4·70	4·01	1·02	3·57
Horizon Cir. Hd.	526·8 ±1·19	555	495	13·5	2·56	1·01	11·29
Sagittal Arc. ...	337·3 ±1·09	370	305	12·30	3·64	1·60	9·42
Trans. Arc. ...	319·5 ±1·03	355	285	11·60	3·63	1·44	8·98

Table 2, shows the mean values of different indices with their respective probable errors, mean deviation, sex ratio, standard deviation and coefficient of variations of the Kol.

TABLE 2.

	Mean with probable error.	Standard deviation	Coeff. of variation	Sex ratio	Mean deviation
Length Br. Index of Hd.	75·4 ±0·28	3·17	4·20	0·98	2·60
Length Ht. Index of Hd.	71·1 ±0·35	4·04	5·68	0·97	3·17
Sup. Fac. Index ...	44·3 ±0·32	3·68	8·30	1·0	2·75
Total Fac. Index ...	86·7 ±0·49	5·56	6·41	1·01	4·78
Nasal Index ...	78·6 ±0·77	8·71	11·08	1·02	6·88
Orbit. Nas. Index ...	115·3 ±0·36	4·11	3·55	0·99	3·37
Trans. Front. Index	74·1 ±0·24	2·72	3·67	1·00	2·19
Vert. Cephl. Index.	87·5 ±0·61	6·84	7·81	1·04	5·43
Trans. Ceph. Index	95·1 ±0·24	2·87	3·01	1·01	2·41
Zygom. Front Index	78·0 ±0·26	2·96	3·79	0·98	2·33
Zygomat. Mandib. Index.	75·3 ±0·26	2·95	3·91	0·97	2·43

Table 3, shows the association of different types of head with different types of nose and their percentages of the Kol.

TABLE 3.
Form of Nose.

Types of head	Leptorrhine	Mesorrhine	Platyrrhine	Hyper Platyrrhine
Dolichocephal ...	9·4	29·1	14·2	—
Mesocephal ...	6·1	26·8	7·8	1·6
Brachycephal ...	...	4·7	...	—

Table 4, shows the association of different types of head with different types of total face and their percentages of the Kol.

TABLE 4.
Form of the total face.

Types of head	Hyper Euryprosop	Euryprosop	Mesoprosop	Leptoprosop	Hyper Leptoprosop
Dolichocephal ...	4·7	14·1	12·5	13·3	9·4
Mesocephal ...	3·9	10·2	11·0	11·0	5·5
Brachycephal ...	—	0·7	—	2·4	1·6

Table 5, shows the association of different types of head with different types of stature and their percentages of the Kol.

TABLE 5.

Nature of the Stature.

Types of head	Very short	Short	Below medium	Medium	Above medium	Tall
Dolichocephal	0·7	22·0	13·3	9·4	6·1	1·6
Mesocephal	1·6	19·6	11·0	4·7	2·4	2·4
Brachycephal		1·6	2·4	—	0·7	

Table 6, shows the association of different types of nose with different types of superior facial character and their percentages of the Kol.

TABLE 6.

Different types of superior facial character.

Form of Nose	Hyper Euryen	Euryen	Mesen	Lepten
Leptorrhine ...	1·6	7·1	4·7	1·6
Mesorrhine ...	12·5	40·1	7·8	—
Platorrhine ...	15·8	6·1	2·4	—

Table 7, shows the association of different types of nose with different types of total facial character and their percentages of the Kol.

TABLE 7.

Different types of total facial characters.

Types of nose	Hyper Euryprosop	Euryprosop	Mesoprosop	Leptoprosop	Hyper Leptoprosop
Leptorrhine		0·7	2·4	6·1	5·5
Mesorrhine	2·4	14·9	18·0	15·8	9·4
Platorrhine	6·1	7·8	3·9	4·7	1·6

Comparative Table 8 shows, the average of the different castes and tribes and the position of the Kol, particularly in respect of the cephalic index, nasal index and stature.

TABLE 8.

Comparison of the different somatic measurements of the Kol with the various castes and tribes of India.

Castes and Tribes	Locality	No. of subjects measured	Average cephalic index	Average nasal index	Average stature
Behari Brh.	Behar	67	74 9	73·2	1661·0
Babhan	Behar	59	76·61	74·0	1662·0
Pod	Bengal	100	77·7	76·1	1625·0
Pod	Bengal	50	77·6	71·81	1628·0
Goala	Bengal	41	77 3	74·2	1646·0
Muchi	Bengal	27	77·6	74·9	1641·0
Babhan	U. P.	26	73 3	73·0	1660·0
Brahman	U. P.	100	73·1	74 6	1659 0
Kayastha	U. P.	100	72 6	74 8	1648·0
U. P. Brahman	Agra & Oudh	50	72·48	69·56	1654·78
Chitpavon	Bombay	103	77·49	73·27	1646·61
Brahman Prabhu	Bombay	55	77·23	71·54	1639·71
Karada Brh.	Bombay	48	76·38	72·27	1639·31
Saraswat Gour Brh.	Bombay	50	77·42	71·18	1629·76
Malve Brh.	C. P.	50	74·30	72·92	1643·56
Baghel Rajput	C. P.	50	76·28	70·42	1691·86
Miscellaneous Rajput	Agra & Oudh	50	74·98	70 03	1684·42
Telegu Brh.	S. India	50	74 39	73·70	1645·0
Telegu Non Brh.	S. India	50	74·27	74·93	1650·0
Nambudiri Brh.	S. India	55	72·51	72·28	1635·55
Nair	S. India	60	74·18	72·37	1689·97
Iluva	S India	50	73 38	75·20	1594·90
Tamil Brh.	S India	50	77·36	71 92	1640·68
Orissa Brh.	Orissa	43	77·31	70·46	1642·92
Goala	Behar	100	76·2	76 7	1642·0
Kurmi	Behar	71	75·7	78·5	1630·0
Kohar	Behar	56	76·1	79·7	1624·0
Maghaya Dom	Behar	100	76·2	82·4	1648 0
Dosadh	Behar	100	76·8	82·4	1620 0
Chamar	Behar	62	76·0	82·8	1612·0
Musahar	Behar	77	75·7	88·7	1591·0
Bagdi	Bengal	97	76·3	80·5	1603·0
Bauri	Bengal	20	75·0	84·1	1603·0
Malpahari	Bengal	100	75·8	92·9	1577·0
Male or Asal Pahari	Bengal	100	74·8	94·5	1577·0
Chandal	Bengal	67	78·1	73·9	1619·0
Koibarta	Bengal	100	77·3	76·2	1629·0
Rajbansi	Bengal	100	75·2	76·6	1607·0
Sadgop	Bengal	48	77·6	73·9	1633·0
Chakma	Bengal	100	84·3	84·5	1595·0
Santal	Bengal	100	76·1	88·8	1614·0
Bhuiya	Chotanagpur	100	76·0	88·7	1577·0
Kharia	Chotanagpur	78	74·5	88·5	1601·0
Kharwar	Chotanagpur	100	75·5	89·7	1605·0
Kurmi	Chotanagpur	100	75·7	82·6	1608·0
Lohar	Chotanagpur	73	75·3	86·7	1621·0
Munda	Chotanagpur	100	74·5	89·1	1589·0
Oran	Chotanagpur	100	75·4	86·1	1621·0
Barhi	U. P.	33	71·8	80·8	1637·0
Bhar	U. P.	100	73·5	81·9	1612·0

TABLE 8—(*Contd.*)

Castes and Tribes	Locality	No. of subjects measured	Average cephalic index	Average nasal index	Average stature
Chamar	U. P.	100	72·8	86·0	1630·0
Chhatri	U. P.	100	73·0	77·7	1661·0
Dom	U. P.	100	74·8	83·0	1655·0
Goala	U. P.	100	73·0	80·9	1628·0
Guria	U. P.	100	72·4	82·6	1627·0
Kachi	U. P.	100	72·1	82·9	1642·0
Kanjar	U. P.	103	74·7	78·0	1636·0
Kewat	U. P.	100	72·7	81·4	1626·0
Koiri	U. P.	100	72·1	83·6	1628·0
Kol	U. P.	32	72 4	82·2	1650·0
Kurmi	U. P.	100	73·3	79·2	1642·0
Lodha	U. P.	100	72·6	83·4	1628·0
Lohar	U. P.	45	72·8	82·4	1636·0
Musahar	U. P.	18	74·1	86·1	1598·0
Pasi	U. P.	100	72·6	85 4	1639·0
Tharu	U. P.	65	73·9	79·5	1614·0
Kammalaus	S. India	40	75·0	77·3	1597·0
Pallis	S. India	40	73·0	77·9	1625·0
Pariahs	Bombay	—	73 6	80·0	1621·0
Nagar Bhr.	Bombay	105	81·38	69 05	1648·60
Bania Jain	Bombay	99	80·58	70·26	1642·69
Audich Brah.	Bombay	93	78·77	69·70	1647·82
Kathi	Bombay	40	80 71	66·38	1670·05
Brah. Kshatri	Bombay	31	79·70	65·84	1639·52
Deshestha Brh.	Bombay	107	78·36	73·41	1636·94
Mahratta	Bombay	59	78·71	72·42	1638·14
Toda	Nilgiri Hill	82	73·3	74 9	1683·0
Kota	S. India	25	74·1	77 2	1629·0
Tamil Chatti	S. India	50	79·49	71·19	1623·0
Kanarese non-Brah.	S. India	50	83·06	72 46	1654·92
Velals	S. India	23	78·2	75·0	1606·0
Paller	S. India	19	77·3	77·0	1610·0
Parias	S. India	28	76·1	78 0	1637·0
Poulayer	S. India	16	76·9	76·0	1549·0
Poulayer	S. India	16	71·0	78·0	1550·0
Cheroumas	Trichour Kalpetta	18	75·7	80·0	1552·0
Poulayer	S. India	12	73·8	76·0	1538·0
Tamil Kala	S. India	40	75·26	76·26	1661·90
Malankuravan	S. India	120	74 0	88·5	1552·0
Kanikkar	S. India	214	74·2	90·8	1534·0
Kol	C. P.	127	75·4	78 6	1608·8
Kanikkar	Travancore	140	74·26 ±0·31	80·11 ±0·65	1531·73 ±4·27
Kuravan	Travancore	19	74·91 ±0·62	79·72 ±1·72	1563·53 ±11·59
Malapantaram	Travancore	37	77·09 ±0·60	71·96 ±0·95	1555·08 +9·27
Urali	Travancore	115	72·09 ±0·22	76·23 ±0·82	1544·52 ±6·18
Muthuvan	Travancore	31	72·95 ±0·35	74·40 ±1·04	1574·87 ±8·46
Paliyan	Travancore	47	75·36 ±0·50	74·35 ±1·20	1597·43 ±8·22

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* Averages were taken from the works of Risley, Thurston, Lapicque, Guha, Basu, Sarkar, Chatterjee, Iyer, *etc.*

Table 9 shows, the comparative values, *i.e.*, the absolu:e deviations of the different bes and castes particularly om the Kol, the positive and the negative signs indicate the nature of deviation fro the averages o male Kols.

T 9.

Tribe &	No. of subjs. measured	Mean stature	Mean Auri Ht.	Mean head Lth.	Mean head Br.	Mean Min. Front Br.	Mean bizy Br.	Mean bigo Br.	Mean Int. Orbit Br.	Mean Orbit nasal Br.	Mean nasal Ht.	Mean nasal Br.	Mean nasal Dep.	Mean supr. facl. Ht.	Mean total Facl. Ht.	Mean Orbit nasal arc.	Mean seph. index	Mean Lth. Ht. Indx. Hd.	Mean nasal index	Mean total facl index	Mean zygo facl. index
Kol	127	1608·8	130·2	183·1	0	102·3	131·2	98·9	29·2	101·8	47·6	37·2	17·0	58·1	113·0	117·2	75·4	71·1	78·6	86·7	78·(
Oran	250	+9·2	−9·2	+3·1	2	−2	−0·5	+1·1	+2 9	−8·6	+1·1	+3·0	+0·3	+5·0	+1·3	−11·1	−1·1	−6·1	+4·1	+2·0	—
Munda	250	−27·3	−9·9	+3·8		+0·4	+0·5	+0·6	+3·8	−6 4	+0·8	+2 9	+2·1	+5·0	−2·1	−9·2	+1·1	−6·7	+4·6	−1·8	—
Chenchu	23	+40·7	−9·7	+2·0	·2	+1·5	−2·2	+5·5	+0·8	−4·6	+0·6	+1 7	+4·1	+3·2	−3·8	−8·5	−2·6	−6·0	+2·8	−1·4	—
Illuva	50	−13·9	−10·6	+6·9	·3	−1·1	−2·5	−2·3	+2·0	−2·6	+1·7	−0·3	+6·3	+6·1	+1·6	+6·0	−2·1	+8·1	−3·4	+3·0	—
Hill Mı	—	+18·2	−10·3	+2·2	7	+0·7	+0·9	−10·9	+3·0	−7·2	+1·3	+2 4	−0·7	+7·5	−0·6	−7·2	+0·7	−6·0	+2·9	−1·1	—
B.H. Maria ...	—	+8·2	−13·1	−1·8	·4	−2·2	−0·6	−12·4	+1·2	−9·0	+1·4	+2·6	−1·2	+5·7	−3·4	−9·3	+0·8	−6·3	+4·3	+2·1	—
Bagdi ...	99	−5·8	−1·1	−1·6	·5	−0·9	−3·0	—	—	—	−0·9	+0·9		—			+0·9	−3·0	+1·9	—	—
Pod ...	100	+16·2	−0·1	+0·1	·4	−1·1	−2·0	—	—	—	+1·5	+0·2		—		—	+2·3	−4·3	−2·5	—	—
Pod ...	50	+19·4	−9·6	+0·9	·8	+0·3	−0·5	+1·5	+1·7	−5·0	+3·5	−0 6	+7·0	+8·8	+3·5	−7·9	+1·7	−5·5	−6·8	+3·1	—
Sadgop ...	48	+24·2	+0·5	−0·5	·1	−1·4	−3·5	—	—	—	+2·0	−0 5					+2·2	−4·4	−4·7	—	—
Baoria ...	20	−5·8	−1·8	+1·9	·9	+0·2	—	—	—	—	−0·5	+1·6	—				−0·4	−3·3	+5·5	—	—
Kaibarta ...	100	+20·2	−0·1	−0·8	·1	−0·3	−2·7	—	—	—	+0·4	+0·6	—				+1·9	−3·7	−2·4	—	—
Muchi ...	27	+25·2	−2·1	−0·3	·7	+0·7	+0·3	—	—	—	+1·8	+1 1	—				+2·6	−2·4	−1·1	—	—
Malar ...	—	−42·4	+3·3	+1·1	·8	−1·8	−0·3	−0·2	+4·4	−0·3	0·4	+2·4	+2·	+	−4·2	−4·6	−0·9	+1·0	+5·7	−3·0	—
Bhuiya of Mayurbhanj	81	−31·8	−4·2	+0·9	·2·0	−4·3	+0·2	+1·9	+1·8	−1·8	+2·4	+0·8	+1·		−3·8	−7·2	+1·6	−2·1	−1·6	−2·7	—
Kharia ...	78	−7·8	−0·4	+1·3	0·6	−1·3	−0·4	—	—	—	−2·3	+2·9	—				−0·9	−4·8	+6·9	—	—
Santal ...	100	+5·2	−1·7	+1·7	·2·7	−0·2	+1·3	—	—	—	−1·9	+3·4	—			—	+0·7	−3·5	—	—	—
Dosadh ...	100	+11·2	−2·4	+1·7	·3·8	+0·5	+2·0	—	—	—	−0·6	+1·4	—			—	+1·4	−0·5	+3·8	—	—
Chamar ...	62	+3·2	−1·4	+1·3	2·3	−0·1	−0·2	—	—	—	−1 6	+0 9				—	+0·6	−2·7	+4·2	—	—
Kol ...	32	+41·2	−3·0	0	5·4	−5·2	−0·4		—	—	−3·6	−1·0				—	−3·0	−10·7	+3·6	—	—
Lodha ...	100	+19·2	−0·8	+2·1	3·5	−3·7	−1·0		—	—	−6·0	−2 7		—		—	−2·8	−10·2	+4·8	—	—
Tharu ...	65	+5·2	+0·4	+0·9	2·0	−2·7	−1·5		—	—	−2·2	−1·1		—		—	−1·5	−10·2	+0·9	—	—
Chura . .	80	+57·2	+2·5	+3·6	0·9	+5·9	1·6		—	—	+ ·4	−1·1	—			—	−2·0	−7·4	−3·4	—	—
Rajbansi ...	100	−1·8	+0·5	+3·1	·2·2	−0·2	0·8		—	—	+ ·3	+0·3	—	—	—	—	−0·2	−4·6	−2·0	—	—
Kanarese N.B	50	+45·2	−7·9	−3·8	10·7	+1·8	·2·5	0·8	+1·3	−1·	+ ·9	−0·8		+6·9	+2·1	−5·6	+7·6	−2·8	−8·6	−14·3	—
Baghel Rajput	50	+83·0	−9·1	+4·3	·4·7	+0·1	2·8	+1·4	+0·5	−6·	+ ·1	−0·3		+9·2	+3·3	−8·3	+0·8	−6·4	−6·8	−16·3	—
Oria Brhn. ...	143	+34·1	−1·8	0	·3·3	+0·5	0·5	+1·6	+2·9	−4·	+ ·1	−0·9		+8·3	+3 4	−7·4	+1·9	−0·7	−5·8	+2.5	—
Malvi Brhn. ...	50	+34·7	−11·1	+3·8	·0·8	+0·5	0·3	+2·7	+2·3	−3·	+ ·0	+0·3		+8·4	—	−5·5	−1·1	−7·5	−4·5	−13·8	—
Kurmi ...	100	−0·8	−4·7	+2·5	·2·5	+0·2	1·3	—		—	− ·4	+1·8		—	—	—	+0·3	−1·9	+4·0	—	—
Kahar ...	56	+15·2	−0·9	+3·0	3·7	−0·6	·1	—		—	+ ·4	+1·1				—	+0·7	−3·7	+1·1	—	—

Comparative Tables 8 and 9 point out that except in the higher castes and in the Mongoloid groups mentioned in the tables, no appreciable differences are present among majority of the tribes noted therein. It should be remarked that certain differences which are noticed among them are not due to distinct racial origin of those tribes but are as a result of miscegenation in different degrees with the basic types. The mixovariant types found among them might be as a result of luxurisation caused by favourable unions. Food and environmental factors inbreeding due to remaining in isolation for a considerable length of period, natural selection and also mutation affected the hereditary condition and caused hereditary variability. It might be pointed out that the frequency of genes may increase or decrease in a locality not because it confers some advantage or the reverse ; but simply because of accidental or chance of fluctuation which are much more serious in a small population than in a large one. The shape, the contour and other proportions of the head remained constant to a certain extent and the high variations which were noticed were due to dominant character of the genes or might be the result of favourable union. It was also observed that certain basic character either remained recessive or dominant. Detailed analyses of the somatometric family data of cephalic and nasal indices reveal the existence of differences in nose among the children of the same parents and these differences are proportionate among certain members while disproportionate in others. It was also noticed that the parents with the same head form, that is index, had quite a different hereditary constitution of the index, though in those particular families, parents have indices which differ very little, still the indices of the children show a large divergence. It was also observed that the parents having a high index, the differences between the indices of the children were moving between higher values than that of the parents with a lower index. Such cases point out the existence of the hereditary variation. It was further noticed that the index might vary either towards positive or negative direction and even appreciably augmented in the cases of luxurisation. As the indices of the parent are not genetically pure, so there were the chances of variation, the presence of a little difference in indices, *viz.*, head index, nasal index, *etc.*, which are noticed among the tribes might not indicate a real difference, as the diameter of the head and the cephalic index, nasal height and nasal index respectively depend on many factors. A number of anthropometrical measurements were often found to be an artificial simplification made to approach more closely to those regions, which were physiologically and embryologically individualized. It may be added that the head form is not a single factor in the Mendalian sense, and in matters of variability, there are still more phenomena for which there were no Mendalian explanations as there was a large nonhereditary variability such as segregation, selection, *etc.*

It might be pointed out that the extreme phenotypical variations could have a different hereditary constitution and the dominance of the higher index over the low, such as Brachy over Dolicho, and also the reverse dominance, which might be due to the prepotence of the parents, as prepotence also cause selection. It must be remarked that in cases like these there must be some distinction between selection based upon prepotence and selection based upon the meeting of many hereditary factors in a homozygotic form. The reason inbreeding modifies the proportion of geno-type and pheno-type is fairly to understand on genetic principle. It was observed that the close relatives are more likely to be of the same genotype than the unrelated members of the population, and thus inbreeding signifies that matings of dominant with dominant, or recessive with recessive, and of heterozygote with heterozygote, will be more frequent than other matings.

Baur, Fischer and Lenz are of the opinion that the same ratio of head breadth to head length can be the result of quite different bone formation in different human races. It may be pointed out that such different bone formations are the result of different combination of genes. It was observed that change is only brought about by other agencies such as mutation, selection and genetic drift. Some are of the opinion that inbreeding in human population would bring harmful effect, but uptil now, no definite proof had been adduced. Selection acts to a certain extent in human population, as a result of which such harmful recessives would be eliminated and the ultimate effect would be beneficial. It should be remarked that all the four of our evolutionary mechanisms probably operated in the evolution of actual population, *viz.*, mixture, mutation, selection and genetic drift. Mutation might have provided mutation pressure and directed the growth of different racial types. Davenport remarked that the effect of intermixture between the Australian and white people was that the shorter arm, leg and broader head of the white tended to predominate in the offspring, but the narrower shoulders dark hair and eyes of the Australians predominated. Stature, body weight and skin colour are influenced by certain differences in the environment. Stature is also influenced by the internal secretion, the thymus, the pituitary and the gonads or reproductive glands. If the function of these glands are disordered, the result is the production of a giant or of a dwarf as the case may be. The relative proportion of the parts of the body and limbs are likewise effected in this way. We do not know how many genes are involved in the inheritance of stature nor do we know exactly how they operate. The total height of a man is made up of the combined heights of the head, neck, trunk and legs. Devenport in his study of the inheritance of stature found some correlation between some of these variables, he thought that shortness was due to the presence of certain genes which inhibit growth and believed that the factors for tallness were chiefly recessive.

Weidenreich offered various bits of evidence indicating that the head form of the human race in various parts of the world has been changing from dolichocephal to brachycephal and is apparently still changing today.

Since skull form is determined by a number of different genes we cannot treat the brachycephal and the dolichocephal as if they were the result of a single Mendelian pair of genes.

The comparative Table 9 shows, that the differences were not remarkable in the majority of the somatic characters among the tribes mentioned except in a few characters, such as, stature, auricular height, total facial and superior facial heights, *etc.* It might be pointed out in this connection that the variations, which were observed among the tribes, *vide* Table 9, was not altogether beyond the range of variations, which were generally to be found present in the same tribes, which would be clearly evident from the data of the somatic measurements collected by different anthropologists. Until further investigations are conducted on uniform methods, eliminating personal equation, it could only be a matter of conjecture, how far such inter-tribal variations were due to the technique followed by different investigators or to the conditions of sampling, or to the paravariational circumstances, such as differences in food, habits and manners of life or to the operation of the selective process on the population. As the relative difference Table 9 pointing out that it was not altogether improbable, that the latter factors may not be altogether inoperative, *e.g.*, Malar, Chenchu, *etc.*, but further elucidation of the share of the different factors could only be obtained by elaborate and more carefully conducted research.

Relative deviation Table 9 further indicated the nature of deviation, *i.e.*, whether the characters under comparison deviate to the positive or to the negative direction with the Kol.

It will be evident from the Table 9 that certain characters approach very nearly the Kol, whereas there were others which deviate appreciably. These phenomena only indicate the nature of hybridization and luxurisations, though it is not altogether improbable that different tribes are still retaining the infantile characters in different degrees, which are mistaken to be derived from totally distinct races.

Further, it might be pointed out that simply a somatometric study of the head forms and the physical observations are not enough on which raciological classification can be based. The limb proportions, a detailed serological study, the proportion and position of the facial and body muscles, as well as palmar patterns are also essential to arrive at a definite racial conclusion. As it has been observed, in some cases prolonged isolation and inbreeding had also affected the physical as well as the serological grouping, and intermixture in different degrees had affected the physical as well as the serological types. Consequently some tribes are noticed racially alike or divergent, the factors in operation being either different degrees of prolonged isolation or admixture. In some cases it might also be due to independent mutation which had affected the basic type but the fundamental unity of characters is there.

TYPOLOGICAL ANALYSIS OF THE INDIVIDUAL PHOTOGRAPHS OF THE KOL OF CENTRAL PROVINCE

The analysis of the individual måle Kol photographs, which were taken at the time of the somatometric measurements, showed the presence of the following different types among the Kol : basic aboriginal type, planofacial type, brachycephalic type, oriental type, oriento-aboriginal type, brachycephalic Maratha (physiognomic) type, Rajput type, Mongoloid type and Mixovariant type. These various types are due to the admixture in different degrees amongst different types. It was evident from the above, and in addition to that from the results of the analysis of the somatic data, that a tall statured type having long headed, association with leptorrhine and leptoprosop and a medium statured people having broad headed associated with leptorrhine and messorrhine characters had contributed considerably in the formation of such types. The following distinctive features, *e.g.*, leptoprosop, hyper-leptoprosop, lepten, leptorrhine and tall statured and brown complexion which are observed among them, indicate that a Northern Indian type of people, such as Rajput, possessing the aforesaid somatic characters, might have contributed to a certain extent in the formation of such types, apart from other Northern Indian types. Further, the presence of the Mongoloid features, such as the oblique eyes, high cheek bones, yellowish tint, scanty beard and body hair, and flat face which are noticed among them, indicate the presence of Mongolian admixture. A question might arise whether these Mongolion features are due to Mongoloid admixture of the prehistoric Mongolion invasion or an independant mutation as the Bushman or not. Various theories were put forth by different Indologists and anthropologists as to the origin of the Mongoloid racial substratum present among the Indian population. Robert Heiné-Gildern was of opinion, that the race Mongoloid must have had formed a very ancient bed as in Eastern Asia, he added that successive invasion must have broken the unity of this ancient ethnic bed and have also destroyed the anthropological purity. The purity of this type as being represented by the Khasi, the Riong, the Palang, the Mon and perhaps the Khmer and the Annamites. Heiné-Gildern further supported the hypothesis of Eickstedt regarding the ancient ethnic bed of India, *viz.*, (i) the very ancient was made of the elements Melanides and Weddoides, (ii) the bed Dravidienne (Indide Mediterranean) and (iii) the bed Mongolide. The last bed represented the Austro-Asiatic element. Sylvain Lévi from the semblance of certain words and legends present among the Austro-Asiatic speakers, opined that before the Dravidienne Invasion, India was inhabited by the Austro-Asiatic people and subsequently the Dravidas and the Indo-Aryans entered this land. At the present moment we do not have sufficient convencing material at our disposal from which we may arrive at a definite conclusion. The question should therefore remain open. Further, it should be pointed out that the analysis of the different photographs as well as the somatometric data and observations do not support the prevalent theory of the Proto-Australoid origin of the majority of the Indian aboriginal population.

An analysis of the individual photographs of the Senoi, an inhabitant of Malaya, published by Martin and their comparison with the photographs of the Kol, reveal that in the majority of the physical characters, the Senoi and the Kol were alike which indicate the presence of the same racial strain among them. Various specific names were given to the type of Indian aborigines by different anthropologists, *viz.*, the Pre-Dravidian, Proto-Australoid, Veddoid, Melanid, Nisad, Gondid, *etc.*

It must be remembered, however, that the term Nisad was used by the ancient Indians to signify tribes having certain common physical characteristics, though in a loose sense. The founder of the "*Nisad Bhansa*" (Nisad family) as described in the Harivamsha, was a very short, a very dark person differentiated from the Dhibaras and other Vindhya-Nilayat besides Tusharah and Tumbaran population, who were addicted to "Adharma" or sins. All these originated from a common ancestor, King Vena. The commentator Neelakantha, interpreted the Dhivaras as "Navikas" or boatmen but the term was generally significant of the Kaibartas. According to him the Tusharah and Tungarh were "Mlechcha" (unclean) population, inhabiting the frontiers. Of these the Tusharah had been identified as Tokharas. Neelakantha interpreted Bindhya Nilayat or peoples autochthon of the Vindhya, as people of the central country known as Gonds and Kols. When we used the term Nisad in a racial sense, its significance must be strictly limited and applied to a racial type, having certain common physical characters, irrespective of the tribal affiliation. In case, the existence of one or more well-defined aboriginal racial types are demonstrated by further research, it would be convenient to signify the tribe described by me as Nisad, and the subsequent additions being conveniently indicated by different numbers.

Comparative Table 10 shows, the mean values of different measurements of the Kol and that of the Australian tribes measured by Wood Jones[1] and Camp Bell, Spencer and Gillen.

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[1] Jones, F. W. and Campbell, T. D., Trans. and Proc. of the R. S. of South Australia, Vol. XLVIII, p. 309, 1924.

Table 10.

Tribe	Kol		Australian Wood Jones & Campbell List I		Australian Spencer & Gillen List II		Australian different tribe Spencer & Gillen		Australian Sterling E. C. i.		Australian Burston	
	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.
1. Stature	1608	1573	1652	1543	1663	1568	1714	1591	1671	1543	1706	1570
7. Head Lth.	183	174	195	176	189	180	192	183	198	...	192	180
8. Head Br.	138	133	143	134	141	136	138	131	138	...	140	133
9. Head Ht.	130	127	122	124	...	...	131	122	114	...	135	133
10. Facial Lth. (Menton-nasion)	...	. .	112	91	82	73	115	105	...	...	117	103
11. Facial Ht. (Menton-nasion)	..	...	192	169	196	170	...	...	...	...	...	...
12. Max. Bizy. Br. ..	131	124	137	126	142	131	133	122	138	...	139	127
13. Diameter Facial (Min. Front Br.)	102	102	114	110	109	107	...	...	...	...	...	109
14. Bigo. Diam.	99	95 9	106	97	98	94	105	96	...	...	105	96
15. Max. Inter. Orb. Br. ...	...	...	110	104	...	...	107	103	...	...	106	99
17. Min. Inter. canthal ...	29	29	36	34	...	...	35	33	...	...	37	35
18. Bi-orbit. nasal arc ...	117	114·8	134	129	...	...	124	121	...	...	124	114
19. Nasal Ht.	47·6	44·5	49	38	51	46	48	45	53	...	49	45
20. Nasal Br.	37	33·2	50	41	48	43	51	46	46	...	46	41

It would appear from Table 10 that appreciable differences are present in various somatic characters between the Kol and different Australian aborigines, particularly in the following characters, *viz.*, in stature, head length, maximum bizygomatic breadth, minimum frontal breadth, minimum interorbital breadth, biorbito nasal arc and in nasal breadth. The characteristic features of the Australian aborigines are as follows:—

Head form is Dolichocephal, nose is markedly platyrrhine and the radio-humeral index is dolichokerkik, but the tibio-femoral index is markedly dolichocnemic associated with remarkably wide spread nose, and long forearms and remarkably long legs from the knee downwards ; whereas the proportion of the body and the limbs of the Kols were observed well proportioned. Further it was observed that the nose of the Australian aborigin was very broad and flat and its cartilagas correspond very closely to those of the Negro in shape. In the Australian, the skull tended to be orygmocraspedote, and had well developed pre-nasal areas, with the incisor teeth closely approximated to the nose. Further, it had been observed in the skulls, whether of an anthropoid apes or of fossil type of men, certain variations are there apart from other characters, in Prenasalis, and in the lower margin of the aperture piriform, which are chiefly due to the teeth pressure of the upper incisor canine teeth. Moreover, it was observed that nose of the Australian, specially the skeleton of the bony nose differed and the aperture piriformis is amblycraspedote in some cases, whereas in the majority of the Australian aboriginals, skulls in the possession of Burkitt and Lightoller were found to be Bothrocraspedote or Orygmocraspedote.

In the absence of the data of such a detailed analysis of nasal skeleton of the Indian aborigines, and the shape and size of the vestibules of the nose and the peculiarities of the palates specially arching or flatening of the interior portion, detailed body measurements and the position of different muscles, *etc.*, and the absence of atavism or atavistic tendency, it was not desirable at the present stage to correlate the Indian aborigines with the Australian tribes and to call them definitely Proto-Australoid.

The presence of Negrito basic substratum among the Indian aborigines observed by some anthropologists, cannot be fully justified when the nature of evidences present among them are thoroughly analysed. The character of hair present among certain tribes, *viz.*, Kadar, Urali, Kanikkar, *etc.*, is frizzly and not woolly as observed among the Andamanese of Andaman Islands. The percentage of the frizzly hair is considerably very low. The presence of steatopygya is not observed among the female members where frizzly hair is present. As a result of atavism or attavistic tendency the percentage of the wooly hair or frizzly hair would have been more apart from the percentage of other Negrito characters. The presence of such small number of frizzly haired people among the aboriginal population of India does not justify us to conclude the existence of Negrito substratum among the Indian population. The presence of such character among them simply points out either admixture or mutation.

THE SOMATIC CHARACTERS OF THE BASIC ABORIGINES AND THE ORIENTO-ABORIGINAL TYPES

The basic somatic characters of the majority of the Indian aborigines except the Mongoloid group appear as follows after a detailed analysis of the somatometric measurements, observations and the individual photographs. They are Dolichocephalic having short statured, and well proportioned built body, the complexion is chocolate brown and the facial form is broad and associated with a short superior facial height. Flat forehead, having slightly slope, which projected over the eyes. Supra-orbital ridges are slightly marked and the supra-orbital part of the frontal bone is straight and not arcoid. Narrow eye slits associated with slightly oblique dark brown colour are observed. Nasal form platyrrhiny in character and markedly depressed nasal root, along with a very broad bridge at the middle and concovo-convex nasal profile which are in certain cases were found to be pronounced concave. Both the lips, *i.e.*, the upper and the lower are thick and the chin is either retreating, *i.e.*, negative or neutral. But the most characteristic feature of the Indian aborigin was noticed, having a tapering forehead in association with bulging cheek bones, *i.e.*, extremely narrow forehead in proportion to the breadth of the cheek bones and as a result of which the face as a whole appears to be a distinctive appearance, and even the type was recognisable in admixture with a higher type. It appeared that certain basic characters were highly affected due to miscegenation with a higher racial type, particularly the following somatic characters were perceptibly affected due to admixture, *viz.*, stature was observed to become higher similarly the superior facial and the total facial heights are changed, further as a result of the augmentation of the heights of the total facial character and the superior facial height, the nasal height was also proportionately changed towards positive direction, whereas it was observed that the nasal breadth remained unaffected, and consequently the nasal index was influenced to a certain degree. The proportion of the minimum frontal breadth when compared with the maximum head breadth, was also affected whereas the value of the maximum bizygomatic breadth was not appreciably affected. Further, it was observed that instead of a high percentage of retreating chin, the percentages of the neutral and the positive chins became high, similarly the percentage of the medium lips also became higher, *i.e.*, the presence of the medium lips are more prevalent. Eye form was observed to be horizontal but still a slight trace of obliquiety was noticed. Various shades of brown to chocolate brown skin colour were noticed among them but less dark complexion was observed in the case of individuals having predominately high racial admixture. From a very high percentage of the absence of body hair, particularly on the chest, the presence of the percentage of hairy body was observed appreciably high. The depression of the nasal root became shallow instead of markedly depressed nasal root, whereas the nasal bridge was appeared to be straight and convex but less broad at the middle and the nasal depth was also noticed higher.

The characteristic features of the Oriento-aboriginal type were as follows—skin colour was brown and not so deep as the basic type. Stature was found to be varied from 1562 mm. to 1671 mm., whereas the head remained dolichocephal. But the total facial and the zygomatico-frontal indices were observed varied from 84·4 to 101·5 and 75·8 to 80·8 respectively. The racial contour as a whole was found to be long narrow or long oval. Generally medium types of the lip were found among them but the presence of the thick lip was also noticed. The chin was found remained retreating and neutral. The character of the nose was found to be straight or convex and not concave. Lobules of ears remained either joined or free. It was noticed that the total facial and the zygomatico indices varied from 84·4 to 101·5 and 75·8 to 80·8 respectively.

RESUMÉ

It should be observed that the Kols of Central Province (Madhya Pradesh) measured by me were racially a hybrid population and to a certain extent the majority of them possessed the following somatic character. Short stature having dolichocephalic head associated with hypsicephal and the character of the nose was mesorrhine, the percentage being 60·64. The superior facial and the total facial forms were euryen and leptoprosop respectively. The obitonasal character was found to be proopic having percentage 72·44. Deep brown complexion, (von Lushans skin colour chart No. 26) associated with deep dark brown almost black (Martin's eye colour chart Nos. 1 and 2) eye colour. Slightly oblique eyes having percentage 51·2 and straight in character and deep dark brown in colour of the head hair were noticed among them, while the forehead was moderately broad having slight slope. Supra-orbital ridges were not marked in the majority of the cases and only in the cases of twelve individuals the presence of alveolar prognathism was observed. Remarkably depressed nasal root was found in the majority of the Kols and further it was observed that the percentage of the concave nasal bridge with its tips directed upwards, was the highest and nasal bridge was very broad near about the middle having 51·9% and the nasal septum was turned down in the majority of the cases. Both the lips, *i.e.*, the upper and the lower, were thick, precentage being 86·6 and the chins were also moderately broad. Lobules of the ears were joined and small, the percentage being 81·1. The presence of the Darwin's point was observed in the majority of the cases. Squarish form of the facial contours among the Kols was in majority.

In conclusion it should be remarked that except the Mongoloid and certain Northern Indian aborigines remarkable differences in somatic characters are not found among different tribes of India. The majority of the tribes appeared to have been descended of a common ancestral stock, their divergence being the result of long separation, isolation, and inbreeding among isolated groups occupying different pockets, apart from mutation and miscegenation in different degrees with the higher people, which had affected the hereditary condition and caused natural selection and variability. Inbreeding had to a certain extent also modified the proportion of genotypes and pheno types. It should also be remarked that the frequency of gene might have been increased or decreased which was more serious in a small population than in a vast one. The range of difference in different characters present among different tribes was not beyond the range of difference found among the members of the same tribe and family, although the somatic characters of the parents and grandparents of the family were not appreciably different. Atavism or Atavestic tendency does not support the Negrito substratum of the Indian aboriginal population. The presence of a very small percentage of frizzly hair among certain tribes particularly among the Kadar, Urali, Kanikkar, *etc.*, indicates only an admixture or mutation and not a Negrito racial substratum.

Different groups of people of India may be classified in four different racial types on the basis of somatic characters present among them, *viz.*, the basic aboriginal type of people already mentioned by me, may be termed as "Nisada", the Mongoloid group of people as "Kirata", the long headed Proto-Mediterranean group of people as "Dravida" or "Mohenjo-Daro" and the higher types of long and broad headed Indo-Aryan speakers as "Arya", rather than calling them Proto-Australoid, Pre-Dravidian, Gondide, Malide, Veddide, Melanide, Kolide, Indide, Scytho-Dravidian, Proto-Nordic, Proto-Mediterranean, Mongolo-Dravidian and other such names.

Different plates of the Kols appended herewith show the basic aboriginal type and the effects of miscegenation and formation of different types.

EXPLANATION OF PLATES

DIFFERENT TYPES OF THE KOLS OF MADHYA PRADESH

Plate No. I.	Basic Aboriginal type.
,, ,, II.	Brachycephal type.
,, ,, III.	Predominating Mahratha type.
,, ,, IV.	Mongoloid type.
,, ,, V.	Female Kols showing different types.

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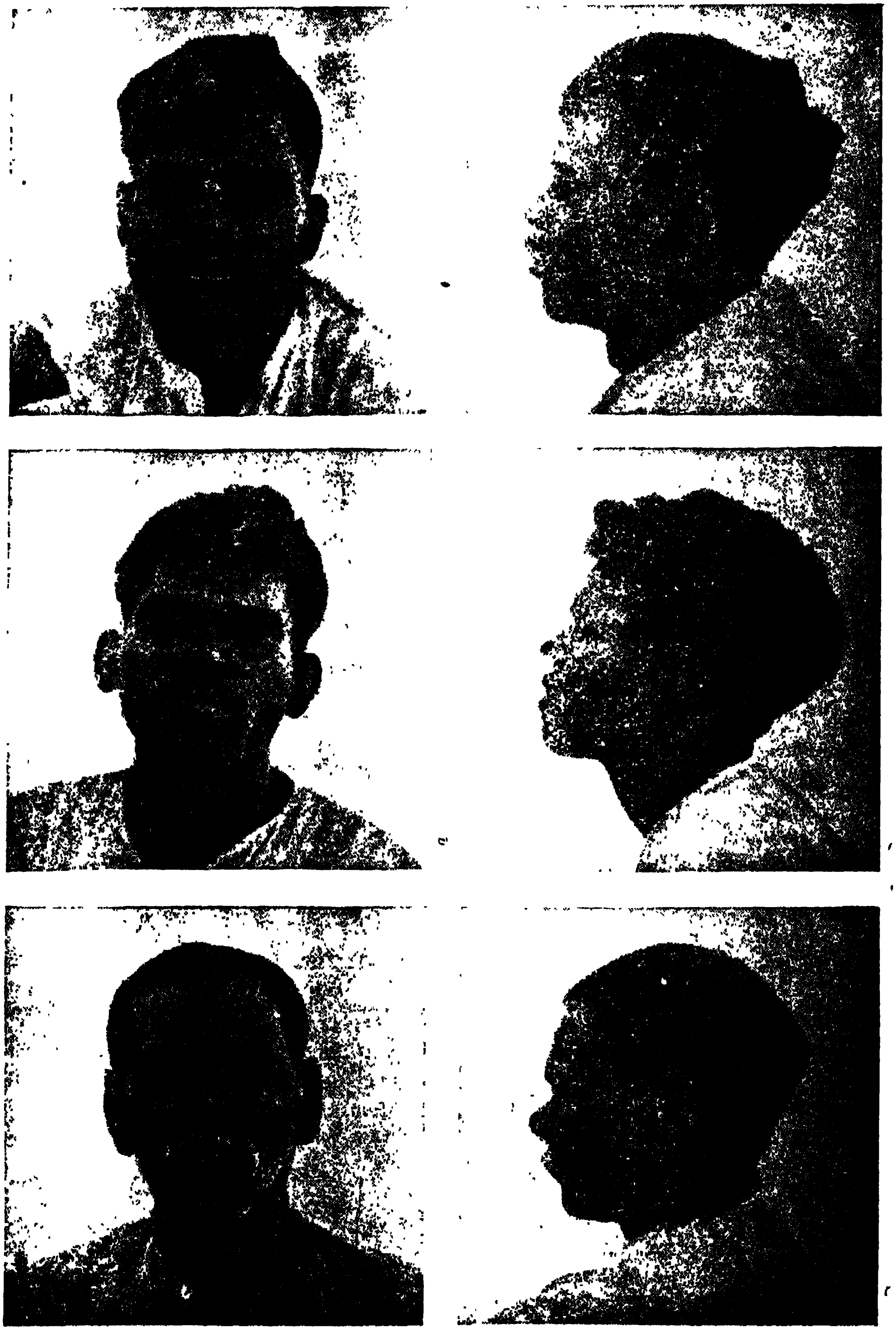

PLATE I.—Basic Aboriginal Type.

Kol

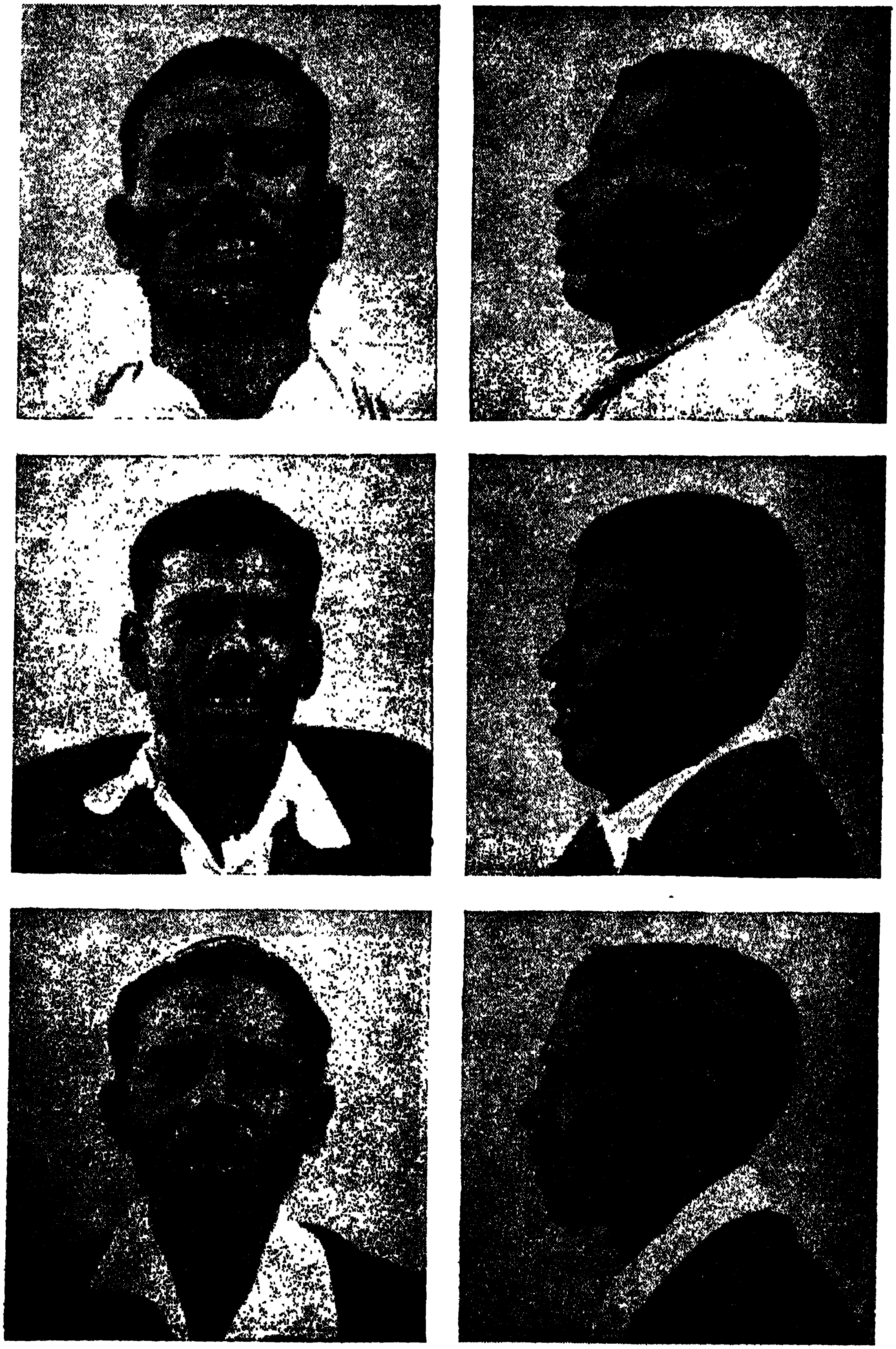

PLATE II.—Brachycephal Type.

Kol

PLATE III.—Predominating Mahratha Looking Type.

Kol.

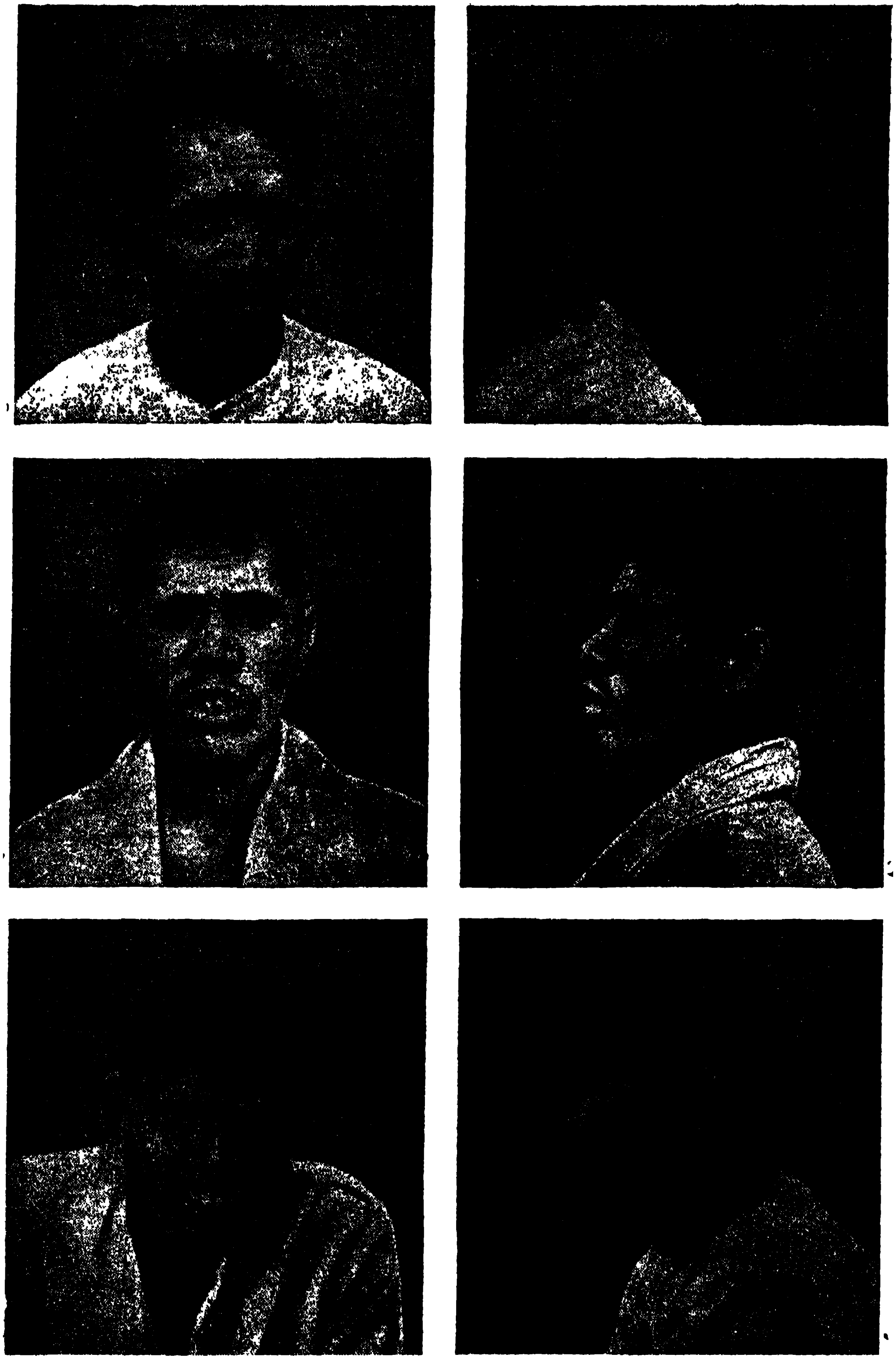

PLATE IV.—Mongoloid Type.
Kol

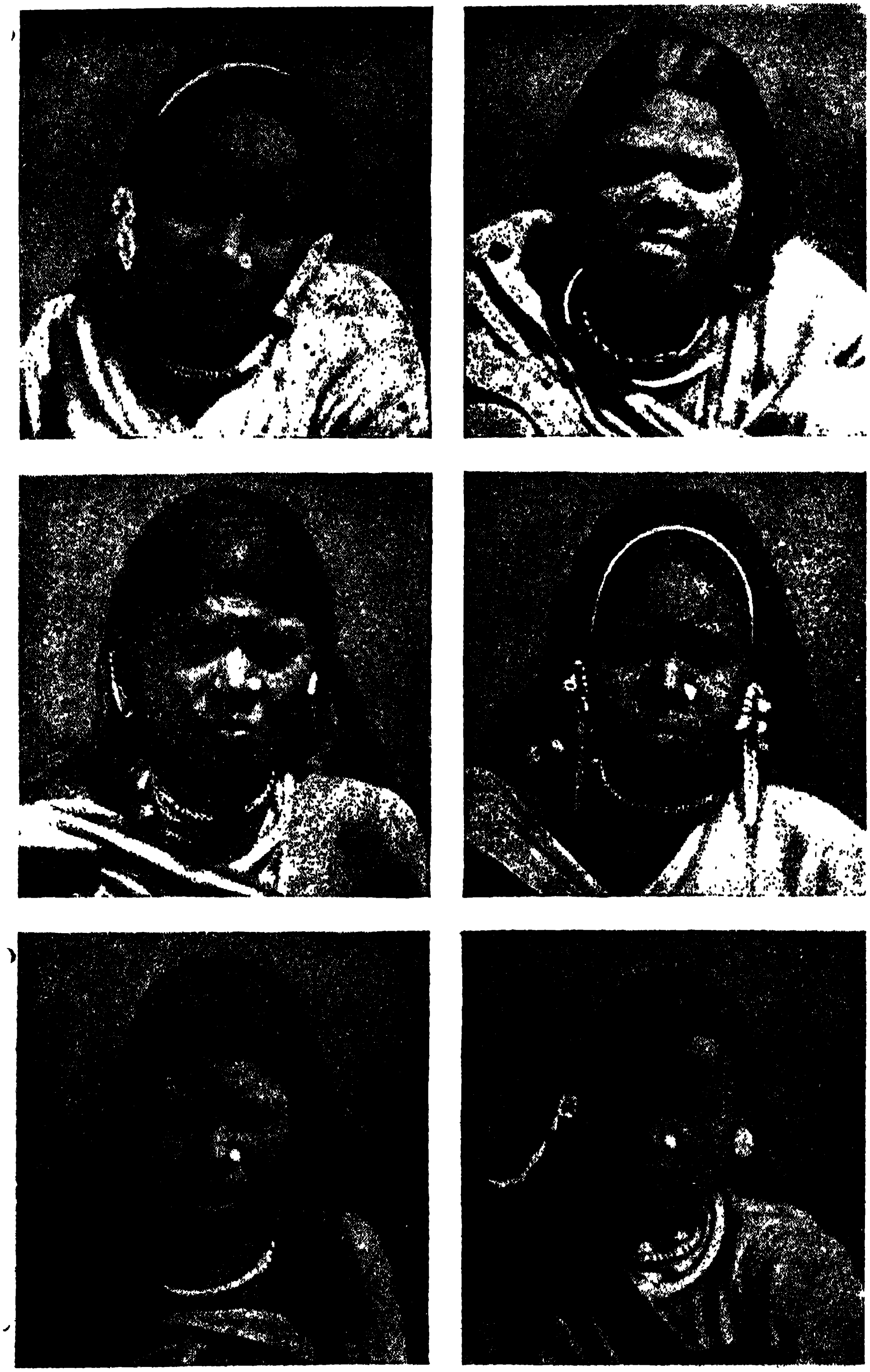

PLATE V.—Female Kols Showing Different Types.

SECTION OF MEDICAL AND VETERINARY SCIENCES.

PRESIDENT: DR. S. K. BASU, M.B., D.T.M., D.P.H., M.SC.,
Ph.D. (EDIN)

PRESIDENTIAL ADDRESS

THE TEACHING OF ANATOMY AND SOME STUDIES ON BONES

LADIES AND GENTLEMEN,

I am deeply grateful to you for the great honour that you have conferred upon an humble student of Anatomy by inviting him to preside over your deliberations in this meeting and for giving him the privilege of addressing you. I consider this invitation as particularly significant because it is perhaps for the first time that a worker from the hall of the "cold cadavers" and its allied fields has been commissioned to take up the onerous duty of the president of your section,

In extending my cordial welcome to you to the business of this section I would place before you my severe limitations. Unlike many of my illustrious predecessors in this chair who could claim to give you a lead and guidance in different branches of medical study, I have come to you as a learner and in the hope of gleaning from your erudite discussions valuable material that would enrich my own poor stock of knowledge. I would therefore request you to give me all the co-operation and support that may make the present session a success.

INTRODUCTION

Before narrating to you some of my own work, you may permit me to give you fragments of my thoughts in connection with undergraduate anatomical teaching for nearly three and a half decades. I have often asked myself as to what is at fault in the very large number of failures that students have in their examination, not only in Anatomy but in other branches of medical study as well, in almost all the centres of teaching in India. The consideration of this question is closely linked with the pattern of our medical education. The formulation of the methods and the creation of the machinery for imparting the practical type of medical education suited to the needs and economy of the country and the genius of its people are very vast problems that have engaged the serious attention of the Government of the country for more than the last ten years and more particularly in the post-Independence period. We can only discuss here very briefly the four fundamental factors which play in undergraduate medical education as a whole, and which influence the teaching of Anatomy in particular. These are, the Student, the Teacher, the Training and the Examination.

SELECTION OF THE MEDICAL STUDENT

The points considered in India for selection of a student for medical studies are (i) his academic achievement at a university examination taken after two years of college training (ii) sometimes a pass in another written examination in physics, chemistry and biology; (iii) a general interview and a physical fitness test; (iv) perhaps a psychological test and (v) last but not the least, political and various extra-academic considerations which, for many years to come, will form a special feature in free India.

In selecting students for medical study, the members of the Admission Committee should have a clear idea of the great "responsibility that devolves upon medical educators of determining who are qualified to study medicine and who are not. All will admit that errors in judgement have excluded from medicine some who are qualified to become physicians and have included some who should not enter medicine" (Johnson).

Alan Gregg (1952) has rightly remarked that "students should be selected in the light of the need for doctors to be socially useful than economically successful. The admitting authorities should pay more regard to their health, motivation, character and probably social usefulness and somewhat less regard to their marks obtained by competitive examinations".

In submitting to you our recommendations for the admission of students to the medical studies, we would refer you to the observations of Gregg and Vengsarkar and to those expressed in 1953 at the first World Conference on Medical Education by Severinghaus (U. S. A.), Brinton (U. K.), Weaver (Canada), Sunderland (Australia), Penas (Phillipines), Misra (India) and finally to what was said in our Presidential Address at the Third Congress of the Anatomical Society of of India (1953) at Hyderabad-Dn.

A. The Admission Committee may be made up of 4 or 5 veteran educationists, one of whom may be a non-medical man. The State may dictate its policy of special representation, but the *selection of the student should be entirely in the hands of this Committee.*

B. The Student :

1. ***The minimum Age of Admission*** of 17 years as is now required in India, is too low. It ***should be raised to 19 or 20.*** This will enable the student either to take his graduation degree in Arts or Sciences or to put in 3 or 4 years of college studies and make him more mature to receive and assimilate fully the training for the medical profession.

2. *Qualifications for Entrance.*

(i) *Academic* : Preference should be given to *graduates* for reasons just given. They should have attended in their college classes instructions in English, Physics, Chemistry (Inorganic, elementary Organic and Physical), Biology with special stress on Mammalian Anatomy and Embryology, Mathematics and elementary Calculus, Statistics, Sociology and Psychology. In the case of students admitted after a two-year college course, they should attend *a further pre-medical course* for one year in such of the above subjects as they did not have in their earlier studies. It is univerally felt that studies as above enlarge the cultural background of a man and make him more fit to adjust himself and respond to diverse social environments which his profession would bring him in contact with.

(ii) *Extra-academic* : Every candidate should be given a long interview to discover his physical and mental *aptitude* and to judge whether he can make an ideal student—cultured broadly in the humanities, intelligent and intellectual, of transparent integrity, humane and sympathetic (Whitby). It may also be remembered that *familial associations* play a big part in determining the attitude of a student.

THE TEACHER

"The ideal teacher would be one who has a broad basis of general culture and a deep knowledge of the subject which he teaches. He must be possessed of the ability to inspire the student with the subject of his teaching. Such a capacity and aptitude can come only from a devoted mind" (Basu). To develop such a mind in the teacher of Anatomy, he must be *a non-practising man with adequate salary and compensatory allowance* to free him from pecuniary worries and enable him to maintain his status at par with his practising colleagues on the clinical side. He will then be in a position to execute his teaching duties and undertake researches in his subject with a warmth that will attract the students to him in ever-increasing numbers and make a success of his toils. The ideal teacher is a ceaseless learner and thinker and a seeker after truth. To get the best out of him, he should be supported and encouraged, not dominated and crushed.

The Staff :

The Medical Council of India has laid down that—

(i) "All teachers in medical colleges must be medical graduates"

(ii) "All teachers of pre-clinical departments must be whole-time and non-practising".

(iii) "The Professor of Anatomy should have a post-graduate/research degree or diploma in Anatomy and acted as Asstt. Professor/Lecturer/Reader for at least five years in a Medical College. The Asstt. Prof./Lecturer/Reader must have similar qualifications as the Professor and must have acted as demonstrator in Anatomy, Registrar/Tutor or an equivalent post in Surgery for at least 3 years in a medical college".

Neither of the above recommendations has been fully implemented in most of the medical colleges of India, because of the lack of properly trained personnel and the funds to pay adequate salary for non-practising posts.

The Strength of the Staff :

The Bhore Committee recommends that there should be re-orientation and re-organisation of teaching, and the emphasis should be shifted from teaching to learning, i.e. such principles and methods of teaching should be adopted as will enable the student "to learn for himself, think, observe and draw conclusions". The Committee also recommends that there should be less of didactic lectures. These two recommendations put together indicate that the teaching should be more personal. The teacher will present before the student the outline of a particular section of a study and ask him to orientate the details by himself. As Anatomy is mostly an objective study, it will not be a big problem to make the student learn in the above way, but the plan obviously involves the appointment of a larger staff than hitherto. The Bhore Committee suggests a teacher-student ratio of 1 : 10. If the students be taken in two batches, this ratio comes up to 1 : 20. For a College admitting 50 students per year the proportion of the grades of teachers should be Professor : Asstt. Professor/Reader/Lecturer : Demonstrator as 1 : 2 : 3, because at least 120 students (1st year and 2nd year students plus failed students) would be working in the whole class. If there be 100 admissions per year the staff, excluding the Professor, should be doubled in the above proportion. Increasing the number of demonstrators alone to make up the numerical strength will not serve useful purpose.

The Terms of Appointment :

All appointments, particularly the senior ones must be on a permanent or a long-term contract basis with prospect of renewal of the contract. There should be *security of service.* The Professor should be allowed to continue till he is 60 years and in some cases up to 65 years or longer (Gregg, Raja). As all pre-clinical posts have to be non-practising, a *graded teaching allowance* should be provided for. In State colleges, a *teaching cadre* should be created to eliminate frequent transfers and dislocation of work. Raja suggests creation of a central cadre to attract youngmen of talent to the medical educational field.

Demonstrators at most places have tenure appointments. They just come and go. The execution of the new idea, of laying the emphasis on learning, thus suffers. We think that their should be two grades of demonstrators, junior and senior. The seniors must be permanent men. The juniors may have a tenure of appointment for 2 or 3 years. On the satisfactory completion of their tenure the junior may be absorbed into the permanent cadre, if there be room available. Temporary and student demonstrators may be recruited from suitable fresh graduates or senior students on small emoluments in the form of stipends. They may help the junior students in their dissection and, in various other ways, relieve pressure on the other teaching staff during rush hours. The prospect of getting such stipends may stimulate the interest of students towards Anatomy and thus be a deciding factor in their choice of a career.

To improve the teaching qualities of a teacher of Anatomy we suggest—

(i) Periodical staff conferences in which, by rotation, a member of the staff has to give a talk on a problem or on the newer method of teaching of a section of the subject. Such talks, involving as they do consultation of many books and journals and close practical observation of various materials, very soon transform the mental horizon of both senior and junior teachers (Ayer).

(ii) Exchange of teachers between Universities.

(iii) Delegating teachers by rotation, as funds allow, to foreign universities to study the newer methods of teaching and research.

(iv) Inviting *Visiting Professors* from other Universities to give talks on their own subjects of interest.

THE TRAINING

The position of medical education in India has taken a newer outlook in the post-Independence period. The country has now to produce only one type of "basic" or highly trained graduate in medicine and has abolished the less elaborate training of the "licentiate" type. To provide adequate medical succour to the growing population of India, estimated to reach 370 millions in 1971, the Bhore Committee

(1946) opined that 185,000 doctors must be given to the country in order to attain a doctor-population ratio of at least 1 to 2000 (in U. K. it is 1 to 1000), in place of the present 50,000 doctors for a population of 350 millions, i. e. a ratio of 1 to 7,000. The annual supply of qualified doctors to the country from the 12 medical colleges and many medical schools in British India was estimated to be about 2,000 in 1946. Since then, 24 new medical colleges have been added to Free India and almost all the schools winded up. The supply position of doctors has therefore not improved very much. To reach an out-put of 4,000 to 5,000 doctors we need to,

(a) Open many more new medical colleges.

(b) Shorten the course of medical studies such that the non-essentials may be eliminated and more time may be allotted to the essentials in preventive, curative and social medicine.

The Bhore Committee Report while endorsing the reduction of pre-clinical teaching considers that the basic doctor should be equipped with such a training that, supported by proper technicians and ancillary personnel, he may be capable of extending his sphere of public utility more widely than heretofore. We cannot therefore give him the merest elements of pre-clinical training in the basic subjects of Anatomy and Physiology, because in his field of work in far away rural areas he will have to turn back on his fundamental concepts and be his own master. The recommendations of the Bhore Committee and the Medical Council of India (M. C. I.) can be carried out only if there is a change of outlook of the general public and the universities towards the method of imparting education, Firstly, the teaching is interrupted by *too many scheduled or unscheduled holidays* which interfere with the courses of instruction. Secondly, some universities (notably those of Calcutta and Gauhati) overload the preclinical period by insisting on teaching of 5 additional subjects. viz. Organic Chemistry, elementary Pharmacology, Pathology, Psychology and Clinical Methods and holding university examinations in Organic Chemistry and Pharmacology. Thirdly, the above universities have divided the 1st MBBS examination into two parts. Part I consists of Organic Chemistry and has to be taken at the end of the 1st year. The students, though they are supposed to carry on their studies in Anatomy and Physiology during this period, do so very perfunctorily, because their primary concern is passing the university examination at hand. The period of study in Anatomy and Physiology in their 2nd year is further shared with four other subjects as mentioned above and they have to take at the end of this year the 1st MBBS, Part II Examination in Anatomy, Physiology and Pharmacology. So really speaking the students get very little time to assimilate the lessons in the fundamental subjects of

Anatomy and Physiology. However thoroughly a student's fitness might have been tested before he was admitted, the purpose of teaching is bound to be foiled by such a short-sighted programme of study and examination. No wonder, therefore, that there is a very high percentage of failure in the 1st M.B.B.S. examination of the above universities.

In giving our following **suggestions and recommendations** in the matter of the period of study and general curriculum as also in special matters concerning the training in Anatomy, we have acted upon the background of the British type of training to which India has been accustomed for more than a century. The American type has occasionally been referred to.

Period of Study.

(a) If Organic Chemistry is to be included in the pre-clinical studies, *its syllabus has to be carefully reduced* and the total period of study not shortened but left at two academic years. In such case the *first six months may be devoted to intensive study of Chemistry and the university examination on it finished* in that time. The question of *taking up in this period further studies in mammalian anatomy and embryology* and in the humanities may be considered as well.

(b) When Organic Chemistry is thus excluded, further pre-clinical study becomes shortened to 18 months as required by the M. C. I. The *first six months* thus devoted to the study of Organic Chemistry may be designated as the PRE-MEDICAL course, the *subsequent 18 months* will be the real PRE-CLINICAL course.

(c) In this Pre-clinical course **Pharmacology and other studies must be omitted** in order that students may be left with only two subjects, Anatomy and Physiology.

The Academic Session should consist of *three terms.* There shall be no holiday in the term-time except the most important National holidays. There may be a short recess of about a week between two consecutive terms and a long vacation of about two months at the end of the academic session.

A **term** should extend over about 3 months. The last week of each term should be devoted to a terminal examination. *Five terms* will thus be devoted to the training in Anatomy and Physiology.

The training in Anatomy is done in India by—

(a) Dissection and other practicals.
(b) Lecture-demonstrations.
(c) Tutorials.
(d) Didactic lectures.

Dissections.

Are dissections necessary? The dictum that anatomy can be taught without dissection and through demonstrations of models, diagrams and dissected parts is a shibboleth. The question was discussed threadbare by the foremost anatomists of India at the 3rd Congress of the Anatomical Society of India, Hyderabad-Dn., 1953. They unanimously held that anatomy could not be usefully learned without dissection. Sir Cecil Wakely, President of the Royal College of Surgeons of England, said at the First World Conference on Medical Education, London, 1953, that "the only way of learning Human Anatomy was by careful dissection of the whole body". It is also agreed that "a complete dissection of human body is a necessary discipline in scientific method and in moulding the mind of the medical student. In India, with the dearth of practitioners of modern medicine every doctor turned out should be prepared to tackle major surgery which would hardly fall to the lot of the general practitioner of Western countries" (Ayer).

Dissections should be carried *throughout the five terms* at the rate of two and a half to three hours each week-day. With the improvement of embalming technique and provision of mortuary coolers there is no point in confining the dissection to a particular season. It is proposed that the students dissect the two "Extremities" in the first two terms of the first year of study and "Thorax" and "Brain and Eye-ball" in the third term. In the 2nd year, the first term is to be devoted to the dissection of "Head and Neck and the remaining Special Senses" and the second to "Abdomen and Pelvis". In the U. S. A., gross dissections are done usually over a period of one and a half terms in the 1st year. In the 2nd year, Neurology and Child Anatomy are sometimes taken for one more term. One or two pairs of students are allotted for gross dissection on a single cadaver. They dissect it systematically without dismembering the limbs or removing the Head and Neck from the Trunk. In this system, the student gets a chance of constantly referring to the structures dissected and their relations and is thus able to carry in his mind a lasting impression of his work.

During dissections, students will be given *lessons on the bones* of the respective parts and lecture-demonstrations by the demonstrator or teacher in charge. Artistic cleaning of structures may be omitted and only their broad features and relations need be displayed.

The progress of the dissection should be from day-to-day and periodically checked by questioning and marking in the dissection card. The students may be asked to draw in a special record book diagrams of structures as they see them in their own dissection. At the end of each term and on completion of a dissection-part, the student will have to take a completion test which may be a written or an oral examination or both. The record of all the work should be kept for reference at the university test.

Demonstrations and tutorial classes should be taken for study of bones, viscera and dissected parts in batches of 10 to 15 students. Diagrams, epidiascopic projections and drawings on the black-board may be utilized for these classes.

Lectures : Didactic lectures should be as few as possible and taken by the Professor and his understudy. Such lectures may deal with the introduction of the study of Anatomy, orientation of structures and their relation in the different parts of the body, applied anatomy and morphology of different parts, embryology, neurology, heredity, genetics and human biology in general. Details of structures may not be given in lectures but a general review of regional anatomy can always be taken up in a synthetic manner. The value of a lecture lies in the integrated idea of a structure or organ that the student can obtain from it and that he could not get by dissection alone.

The Teaching of Embryology is an essential part of Anatomical studies. Only the broad basic facts of the science need be given to the undergraduate student so that he can explain the anomalies that he will meet in later life and understand the genesis of important relations of structures in the body.

The Teaching of Living and Applied Anatomy :—The student has to be guided to supplement his conception of structures that are modified by death and embalming fluids or are not seen at all in the cadaver, by observations on the living model. He has to be taught to use his senses of sight, touch and hearing to conceive of the physical and other features of the living man. A knowledge of surface projections of underlying structures and familiarity with the appearance of anatomical parts under X-rays and other instruments are some of the features that the teacher impresses on the students in this section.

The teaching of Applied Anatomy is a necessary corollary to that of Living Anatomy and should be taken along with the latter.

The Teaching of Histology should undoubtedly be included in the anatomical discipline since, to complete the idea of a structure, one must go into its microscopic as well as its macroscopic appearance. The Physiologist's grouse in this matter may not be beyond conciliation. In fact both the departments of Anatomy and Physiology may take a joint interest in the subject.

The Integration of teaching of Anatomy and Physiology is a matter that is now dominating the thoughts of medical educationists. 'Not only is the integration being carried on as an experimental measure in the pre-clinical subjects but it is also entering into the fields of clinical subjects (Raja). Anatomy and Physiology used formerly to be considered as one unit of study. The unspecialised mind cannot conceive of a structure without caring to know the implications of its functions. The departments of Anatomy and Physiology are, like the siamese twins, interdependent, though separate. For an under-graduate course, the two disciplines can be considered together up to a certain point, beyond which they bifurcate and develop along their own special lines.

The Integration of Pre-clinical and Clinical teaching can only be partial. The pre-clinical student may, for instance, be taken to the out-door or indoor clinics and shown how facts observed on the dead can be transferred on the living with the help of the unaided senses or with instrumental help. Interesting cases of developmental errors will stress the facts of embryology in his mind. Ayer calls such trips to hospital as "clinical excursions", which he arranges "at his place once a week with seven sections of the hospital, viz. General Surgery, Orthopaedic, E. N. T., Ophthalmology, General Medicine, Radiology and Clinical Laboratory and Blood Bank. The students return from the visits to the hospitals with great enthusiasm and an added understanding of the meaning and significance of their non-clinical studies". The clinical students and post-graduates would find it worth their while to visit the Anatomical Museum and dissection hall as often as they can and attend refresher courses or special classes in Applied Anatomy taken by the senior teachers of Anatomy. Anatomists, however, do not regale the other side of the picture, i.e. the clinical specialists giving talks to the pre-clinical student, since such talks are likely to be too over-specialised for the students of basic anatomy.

How much training should be given to the student will depend on the time available. For an under-graduate course broad fundamental facts should be given and minute details avoided for the ordinary student. Whatever is given to him should have a principal bearing on the application that he will make use of in the clinical stage of his study and in his future life as a practitioner. The importance of this training lies not so much in the amount of facts given as in the correlation of individual facts which make up a total phenomenon that abides in the student's memory (Ayer).

For **Post-Graduate** training in Anatomy, laboratory and other facilities are required for more intensive study of the parts dealt with in a simpler manner in the pre-clinical period. **Training in**

Researches in Anatomy requires equipments and facilities which should be provided according to the type of research or the requirements of the Professor under whom the work has to be carried.

A word on **why training and researches in Anatomy have till very recently been poor** in this country may not be out of place here. The question should be judged in the setting of things in British India. Previously, Surgeons used to be teachers in Anatomy and their chief interest lay in Surgery. From the time teaching was transferred to the care of the Anatomist till even now, the control of the sinews for improvement of the department has usually been in the hands of clinicians or clinically-minded authorities who are unimaginative, uninformed and unsympathetic and are either averse or perverse to the development of the department of Anatomy. These high-browed administrators pooh-pooh the idea that the department of Anatomy needs anything more than a few dissection tables and a neglected corner of the college and snub the demand of the Anatomist at every step, for they think that Anatomy can not and should not grow except according to their own liking. As a result of pressure for improvement exerted in the post-Independence period by progressively-minded central authorities, the local authorities in many places have tried to make a move in the matter of equipments and new constructions, but at few places has the departmental head been consulted on or asked to submit his requirements in the design and lay-out of such new constructions or supply of equipments. Great care is taken to announce from the platfom and the press the heavy expenses incurred for the department, but, alas, when one who has an eye to see comes to visit the place he is disillusioned and may be amazed to notice the fundamental incongruities! In addition to this the teaching is chronically under-staffed, the teachers are remarkably under-paid resulting in their inability to concentrate on the teaching on account of various financial worries, the equipments are scanty and the supply of literature and books is anything but progressive or desirable.

THE EXAMINATIONS

This question may be looked upon from the following points of view :—

(A) Is an Examination necessary at all ?

Certainly an examination is necessary but the type to be adopted is a matter of choice. Some are of opinion that there should be no university examination. But you will agree that in order to establish a uniform method of teaching of Medicine for all the States of India, a standardized method of assessing the merit and worth of a candidate can be followed only by insisting on having the university examination.

(B) What should be the type of examination ?

In India and U. K., the 'triple' type of examination is the prevalent one and consists of written, oral and practical tests in which the two latter are together given the same value as the written one. In some universities, the day-to-day record of the candidate is given as much worth as the 'triple' test and is considered separately for a pass. In Italy and the Scandinavian countries there is no written test, the examination being chiefly oral and occasionally combined with a practical one (Viswanathan). In some European countries, in addition to the oral and practical tests, the writing of a thesis or dissertation is necessary for the written test.

Our Recommendations :

The prevalent system of 'triple' examination in our country encourages cramming and display of feats of memory which mostly fade out in a short time. We recommend that—

(i) Record of day-to-day work and progress and credits at terminal and periodical examinations in the college should be given the utmost stress in all universities. Performance at university examinations should be made complementary to the above. The students should be required to pass in both.

(ii) More stress should be laid on the oral test and the marks on this and practical and written tests should respectively be in the proportion of 40, 30 and 30%. The passing marks should be 50% in each of the oral and practical tests, 40% in written test and 50% in aggregate.

(iii) The **Compartmental** system of examination should be universally adopted. The student will repeat only the subject in which he failed in a previous examination.

(iv) To prevent the huge National loss entailed by **chronic students,** there should be rigid **weeding out** of the unfit in the very first year of medical studies. Not more than two chances should be given to a candidate to pass his pre-clinical examination. The pruning should be less drastic in subsequent examinations.

(v) Selection of Examiners and Paper-setters.

None but persons of the rank of Professor/Reader/Lecturer of a minimum teaching experience of 10 years in the subject should be appointed as an Examiner. There should be an **internal examiner,** who is a senior teacher in the subject and an **external examiner,** who should also be a teacher preferably recruited **from another** university.

The setting of the question paper may be done by either or both of them or by a **third external** teacher of the subject who is not otherwise connected with the examination.

The examiners and paper-setters must be **current teachers** or those who had been connected with active teaching within the last 5 years. The M. C. I. recommends that "when there are more than 2 examiners one may be a surgeon who had not more than 3 years previously been a teacher in Surgery". In Anatomy, *all questions* in the "Written" paper should be *compulsory* and so framed as to cover a knowledge of all parts of the human body including applied anatomy and elementary embryology. The practical examination should be divided into two parts, one part dealing with actual dissection and/or questions on dissected parts, and the other dealing with (i) Living Anatomy in which questions to elicit knowledge of topography and surface-marking, posture and action of muscles etc. may be asked—and with (ii) X-ray Anatomy, in which questions may be asked on radiographic appearance of different parts of the normal body. In the oral examination, broad questions on bones and joints, viscera and special senses, models, sections and diagrams and on elementary embryology may be asked as also simple questions on function, morphology, and applied anatomy. The result of the writen test should be available to the examiners before the candidate would appear for his oral, so that the examiners might have a better chance of judging him.

In the above consideration, the aspect of normal histology has not been taken into account, as the subject is still grouped under Physiology in most of the medical colleges of India.

SOME STUDIES ON BONES

The Mode of Growth of Bones :

The following mode of growth of long bones has been established beyond doubt.

(1) The diaphysis of a long bone grows in length by addition of new bone (metaphysis) derived from ossification of cells proliferating from the cartilage at its end. Ossification also starts independently in the centre of the massive cartilage at articular ends of long bones or in adjacent positions where future tendons would be attached. This forms the **Epiphysis.** A plate of cartilage, **the epiphysial cartilage,** is thus trapped between the ossifying diaphysis and epiphysis. Its cells actively proliferate chiefly on diaphysial side, ossify and increase the length of the diaphysis.

(2) The growth in width occurs from subperiosteal accretions.

(3) Absorption of bone goes hand-in-hand with accretion and occurs as a modelling process on the surface to maintain the shape and mechanics of the bone, and within to enlarge the medullary cavity.

(4) Growth of bone is a surface phenomenon. Interstitial growth or expansion does not occur.

(5) Stoppage of growth in length of a bone is indicated by ossification of the epiphysial cartilage and consequent diaphysio-epiphysial union or fusion, ordinarily known as **epiphysial union or fusion.**

The **facts of epiphysial union** of long bones make an interesting study :—

(i) The *age* when union occurs at an articular end is, under circumstances of normal functioning of the organs of the body, a definite one and is variable within very narrow limits in similar people.

(ii) This age is different in bones at different articulations. A genetic factor seems to control the union at any individual epiphysial region (Rubinstein).

(iii) The *pattern or sequence of epiphysial union* is the same for all animals of the same species, but differs in adjustment to habitat and methods of progression in different Orders of Mammals, and even in the same Order or Sub-order.

Body maturity runs pari passu with epiphysial maturity (Outhouse and Mendel). Variations in age of epiphysial union do occur in the sexes and in the different races, climates etc. But such variations are not fundamental. They may be considered as a total shift, the pattern always remaining the same. Body maturity is similarly influenced by sexual and climatic conditions. It is no wonder therefore that epiphysial union will be totally advanced in girls who mature earlier than boys, or in people of warmer climates who mature earlier than those of the colder zones. Studies on people migrating recently from a different climatic region will obviously yield different results than those on native people.

A. Studies in Epiphysial Union in Man.

These were done by earlier anatomists through direct observation of sections of bones of man obtained in the dissection halls or on post-mortem tables. The material available for study was so scanty that it was not possible for later observers to verify the results obtained by their predecessors. So, figures for age of epiphysial union were either copied from earlier to later text-books or were not carefully worked out and represented discrepancies as wide as 3 to 9 years (Table I).

A challenge came from Stevenson who made a naked-eye study of 110 age-known identified skeletons collected by the late Prof. T. W. Todd and established a change of conception of the prevalent ideas on the age of epiphysial union. Anatomical authorities soon revised the figures in the text-books in the light of newer work as shown in Table II. Though the figures were generally earlier in this Table than those in Table I by two years, yet the over-all discrepancy remained as before.

A change in the method of observation was introduced since the discovery of X-rays in 1895. It was found that cartilage would not cast a shadow in radiograms whereas bone did, so that the growing end of a long bone showed two shadows, one of the epiphysis and the other of the diaphysis, separated by a space indicating the position of the epiphysial cartilage. This space, clear at younger ages, narrowed and became bridged across by shadows of bony spicules, which marked the *beginning* of fusion. The narrowing and filling up of the space became more marked till the fusion of diaphysis with epiphysis was completed. Pryor was the most enthusiastic of the early investigators by the X-ray method. He was follwed by a host of investigators who took up the study on different cross-sections of adolescent population in different climes. In Table III is given the result of such studies country-wise. Here also there is a discrepancy of 1 to 7 years between different findings of fusion-dates of a particular epiphysis. The following reasons for this anomaly are given.

(i) **Sex**—Pryor (1906) was the first to show that corresponding epiphyses fused two years earlier in girls than in boys.

(ii) **Climate**—Workers in Burma, Egypt and India (Table IV) have shown that epiphyses fuse two years earlier in people of tropical countries than in those of temperate ones. Galstaun (1937) thinks that superabundance of ultra-violet radiation in the tropics increases assimilation of calcium and consequent bone formation.

Criticism of Radiological Method of Epiphysial Investigation—Many observers decry the use of X-rays in epiphysis study. Stevenson condemns a radiograph as "a confusing medley of shadows." Glaister and Brash think that the interpretation of 'super-imposed shadows' of the whole thickness of an irregular disc, like the epiphysial cartilage, observed from the edge is difficult. Sidhom and Derry think that in the explanation of radiographs errors may creep in and there may be wide difference of opinion given by observers on the extent and date of diaphysio-epiphysial fusion. Paterson thinks that an 'epiphysial scar,' which is a line-like mark in the position of epiphysial cartilage seen long after completion of epiphysial fusion, may mislead an observer and lead him to assign too late a date to the fusion.

As against this, Todd, Todd and Todd observe that since diaphysio-epiphysial fusion starts deeply and completes on the surface, so a naked-eye inspection of the part is likely to give a later date for complete union than given by the X-ray study.

In order that the method adopted *for assessment of epiphysial fusion* may be reliable, the worker should have a *careful training in comparison of radiograms* of bones of undissected bodies with actual sections of the same bones (Todd, 1930).

Factors to be remembered in making a chart of epiphysial union from radiographic study—

(1) An accurate *date of birth* of the subjects must be noted. Without this the knowledge gained from the study cannot be applied when necessary.

(2) The subjects are to be drawn from a *homogeneous social community that has been stabilized in a particular climate.*

(3) Subjects must have been in the possession of *good health* since birth, and there must not be any sign of endocrine disturbance.

(4) They must be drawn from economically stable families who live above want. This factor however does not make a very big difference in ultimate appraisement.

How much can an epiphysial radiograph be relied upon as an evidence of age and maturity :

1. **Only pressure epiphyses** are, subject to minor modifications, uniform in their fusion. *Traction epiphyses,* (olecranon, medial epicondyle, trochanters of femur, proximal fibula and calcaneal epiphysis) are unreliable (Stevenson).

2. Since fusion is completed within 6 months to a year of the first appearance of its signs, even incomplete fusion is of value as an age and maturity indicator.

3. "All dates are subject to minor modification and individual variation, of which Hellman calculated standard deviation as 3 months, thus providing a normal limit of 9 months on each side of the mean date. *In the absence of a birth certificate, a given age may refer to any*

TABLE I

AGES OF UNION OF EPIPHYSES AS ASSIGNED BY VARIOUS ANATOMICAL AUTHORITIES BEFORE STEVENSON (MODIFIED FROM STEVENSON)

	HUMERUS			RADIUS		ULNA		FEMUR				TIBIA		FIBULA		
Authority Year	Head.	Dist. Ex.	Med. Epic.	Prox. •	Dist.	Prox.	Dist.	Head.	Ls. Tr.	Gr. Tr.	Dist. Ex.	Prox.	Dist.	Prox.	Dist.	Clavicle.
Bryce (1911)	20-22	17	18	17-19	18-20	17-19	18-20	18-19	18	17	20	19-24	17-19	22-24	20-22	25
Cunningham (1922)	25	16-17	16-17	18	21	17 •	21	18-20	18	18-20	21	21	18	18-20	18-20	22-25
Dixon (1912)	20-25	17	18	18	21-25	17	20	18-20	18	18	23-24	21	17-18	22-24	20	25
Dwight (1911)	20	15	—	16	19-20	16	18	18	19	19	20	21	17-18	22-24	20	25
Gegenbaur (1892)	—	18	—	17	20	17	20	20-25	20-25	20-25	23	—	—	—	—	—
Henle (1871)	—	15	16	16	19-20	15-16	20	20	—	—	—	18-25	18-25	19-25	19-25	18
Krause	22	16-	18	16-	20-	16-	20-	17-	17-	17-	19-	19	17-	19	17-	20-

Lall & Nat M — 16- 17- 16- 18- 17 18-
(1934) 19 18 18 19 19

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(1909)																
Lewis (1918)	20	17	18	17-18	20	16	20	Puberty to		20	20	20	18	25	20	25
Morris (1914)	20-21	17	17	17-18	20	17	20	19	17	18	20	21-25	18	22	20	22-25
Piersol (1918)	20-21	17	17	17-19	18-20	17	20	18	19	19	20	19-20	18	20	18-19	25
Poirier (1911)	20-25	16-17	16-17	16-19	20-25	20-21	22-24	18-22	18-22	18-22	20-24	18-24	16-18	22-23	20-22	25
Terry (1921)	20	17	17	17	20	16-17	18-20	19	17	18	20	20-25	18	22	20	25
Testut (1921)	20-25	16-18	17-19	16-20	20-25	16-20	20-25	18	18	16-18	20-22	18-20	16-18	19-22	18-19	22-25
Thompson (1921)	25	16-17	18-19	18-20	20-25	16	20-23	18-20	18	18-19	20-22	20-24	18	19	19	25
Earliest	20	15	16	16	18	15	18	18	17	16	19	18	16	18	17	18
Latest	25	18	19	20	25	21	25	25	25	25	24	25	25	25	25	25
Difference	5	3	3	4	7	6	7	7	8	9	5	7	9	7	8	7

Lall & Nat (1934)	M	—	16-19	17-18	16-18	18-19	17	18-19									
Pillai (1936)	M & F	17	—	17	17	18	16	18	15	17	17	17	17	17	17	17	—
Earliest	M	14	14½	16	14	16	14	16	15	16	15	16	16	16	14	14	22
	F	14	12	13	13	16	14	16	13	14	13	14	14	14	14	13	20
Latest	M	18	19	19	18	20	20	20	17	17	17	18	17½	17½	17½	18	22
	F	18	14½	17	17	18	16	18	17	17	17	18	17½	17½	18	18	20
Difference	M	4	4½	3	4	4	6	4	2	1	2	2	½	½	3½	4	nil
	F	4	2½	4	4	2	4	2	4	3	4	4	3½	3½	4	5	nil

TABLE IV

AGES OF UNION OF EPIPHYSES AS ASSIGNED RADIOGRAPHICALLY IN DIFFERENT COUNTRIES.

	HUMERUS			RADIUS		ULNA		FEMUR				TIBIA		FIBULA		
Authority Year	Head.	Dist. Ex.	Med. Epic.	Prox.	Dist.	Prox.	Dist.	Head.	Ls. Tr.	Gr. Tr.	Dist. Ex.	Prox.	Dist.	Prox.	Dist.	Clavicle, (St. end)
BURMA																
Barret (1936)	F 18	Before 12	14-16	13-16	17-18	12-15	16-18									
EGYPT																
Sidhom & Derry (1931)	M —	15-17	18-19	16	18-20	14-20	19-20									
INDIA																
Basu & Basu (1935-37)	F 16-17	12-13	13-15	13-15	16-18	13-15	16-18	13-15	14-16	13-14	16-18	15-17	14-16	16-18	14-16	
Galstaun (1930 37)	M 14 18	—	16	16	18	17	18	16-17	17	15-17	16-18	16-17	16	14-16	14-16	22
	F 14-16	—	14	14	16½	15	17	14-15	14	15-17	14-15	14-15	14	14-16	13-15	20
Hepworth (1929)	M 17- & F 18	14½	—	14-15	16-17	—	16-17	15½-17	16-17	—	16½-17½	16½-17½	16½-17½	16½-17½	17-18	—

date during the 18 months which intervene between the birthday next above and half way towards the birth day next below" (Todd, 1930).

A correct appreciation of what has been said above is all that matters to clear up the difficulties that our medical jurists have to face in courts of law. **The following should be insisted upon in india for medico-legal purposes of age-determination.**

1. Reliable radiographs of (a) *elbow* and (b) *wrist and hand* of left side (right side in case of left handed persons) taken in antero-posterior and lateral positions will give us all the features leading to a conclusion regarding enquiries on ages from 10 to 18 years.

2. *Only pressure epiphyses are to be considered.*

3. The appearance of *ossification in the pisiform* bone gives a reliable guidance to the lower age.

The following table calculated from our own work (1938, 1941) on Bengalee adolescents may give an idea of how the assessment may be carried on :—

TABLE V

Radiographic Determination of certain Ages in Bengalees.

Bones concerned	*Male*	*Female*
Appearance of ossification in Pisiform	11 to 12 yrs.	10 to 11 yrs.
Humerus, Distal (epiphysunion)	15 to 16 yrs.	12 to 13 yrs.
Radius, proximal ,,	15 to 16 yrs.	13 to 14 yrs.
Radius, distal ,,	16 to 18 yrs.	16 to 17 yrs.
Ulna, distal ,,	15 to 16½ yrs.	16 to 17 yrs.
First Metacarpal ,,	15 to 16 yrs.	14 yrs.
Distal phalanx, thumb ,,	16 to 17 yrs.	13 to 14 yrs.

The following Table gives some of the critical ages for purpose of the Indian Penal Code and other Acts. It may be read along with Table V.

TABLE VI

Critical Ages for different Sections of Law.

	Section or Act.	*Purpose.*	*Critical age below which Law becomes operative.*	
			Male.	*Female.*
1.	Sec. 361, I.P.C.	Kidnapping a minor boy or girl	16 yrs.	18 yrs.
2.	Sec. 366A, I.P.C.	Procuring for illicit intercourse	—	18 yrs.
3.	Sec. 369, I.P.C.	Kidnapping or abducting for purpose of stealing	10 yrs.	10 yrs.
4.	Sec. 372, I.P.C.	Selling a minor	18 yrs.	18 yrs.

	Section or Act.	*Purpose.*	*Critical age below which Law becomes operative.*	
			Male.	*Female.*
5.	Sec. 373, I.P.C.	Buying a minor	18 yrs.	18 yrs.
6.	Sec. 375, I.P.C. Cl. 5	Rape	—	16 yrs.
7.	Ben. Act II, 1922			
	Sec. 3, Cl. 1	Child	14 yrs.	14 yrs.
	Sec. 3, Cl. 6	Young person	14 to 16 yrs.	
	Sec. 3, Cl. 7	Youthful offender	Under 16 years.	
8.	Child Marriage Restraint Act (Act XIX of 1929)		18 yrs.	15 yrs.
9.	Act VII of 1897, Sec. 4 (A)	For Reformatory Schools	15 yrs.	15 yrs.
10.	Bengal Act II, 1919, 1923	Against Juvenile Smoking	16 yrs.	16 yrs.
11.	Act XXVI of 1928	Employment of children	15 yrs.	15 yrs.

GENERAL OBSERVATIONS ON EPIPHYSIS AND EPIPHYSIAL FUSION.

The following facts based on observations of Parsons (1904-5) are well-known.

Epiphyses are of 3 types

(1) **Pressure** Epiphyses occur at articular ends of bones and represent fulcra of lever systems. They bear great pressure. The early consolidation into bone of their cartilaginous precursors is of top priority in the locomotion of the animal and they will therefore behave uniformly in a group of similar animals.

(2) **Traction** Epiphyses are of the nature of sesamoid bones and may be considered to have developed along attachments of tendons to bones. Their consolidation is important but their behaviour is less uniform.

(3) **Atavistic** Epiphyses are merely reminders of some ancient structral pecularities.

As a result of our work on about 1000 skeletons of various Orders of Mammals in the museums of U. K., U. S. A. and India we have arrived at the following conclusions (Basu, 1945) :—

SEQUENCE OF EPIPHYSIAL UNION

Stevenson (1924) and Todd and his school (1922 to 1938) were strong in their conviction that the sequence of epiphysial union lay in mammals in a genetic factor which formed the chief mammalian trait and which, except for minor variations, was almost immutable. Our observations lead us to conclude that any one schedule of epiphysunion cannot hold true for all land, aerial and aquatic mammals as formulated by the above authors. It is similar in members of the same Species, Genus or Family, but may differ in other Families of the same Order.

Two important principles appear to control the union of epiphyses:

(a) Adaptation of the animal to its surroundings, requiring the use of certain portions of the limb more than or in a different way from the others ;

(b) Use of a limb in a particular way for *countless numbers of generations* produces in the animal a *genetic factor* which controls the sequence of fusion in the epiphyses, whether the animal lives in the same surroundings as its ancestors or has transferred itself to a newer one for a *few immediately preceding generations.*

Similar habitat and habits adopted by members of divergent orders will therefore produce a convergent type of epiphysunion. The biological theory of *Adaption* and *Convergence* is nowhere more applicable than in the sequence of union in *articular epiphyses.*

Acceleration or retardation of fusion of individual epiphyses is linked to certain methods of progression, habits or habitat. Here also the theory of convergence is seen to play its part.

Appreciation of the mechanical factors underlying the priority or delay in fusion in an articular epiphysis will be easy if an epiphysis is considered to be a *protective cap* to the growing end of a long bone and as consolidating the shaft early by fusing with it when strength is more desirable than growth. Thus, terminal phalanges of limbs of all terrestrial quadrupeds have the highest priority in fusion, since in progression they have to dig into the ground or branches of trees and secure for the limb the friction or reaction necessary to overcome gravity. Other phalanges follow sooner or later. Where the limbs have been partially relieved of prehensility e. g. in the prehensile-tailed new-world monkey Cebinae and Mycetinae, this priority will be forfeited.

Almost equally essential in pulling forwards the body and in prehensile acts is the part played at elbow involving the distal epiphysis of humerus and the proximal one of radius. These wrangle with the terminal phalanges for priority, and are often successful e. g., distal humerus fuses earlier than terminal phalanges in Lemurinae, Nyctipithecinae, Cebinae, Cercopithecinae, etc. and proximal radius fuses earlier in Semnopithecinae, Simia and all other scansorial animals.

For a well-coordinated and balanced progression on 4 limbs, the pulling forwards of the body by the forelimbs must be supplemented by pushing or lunging the body forwards. This is achieved by (1) the lifting force of calf muscles acting on heel with the ankle as fulcrum and (2) extensors of hip acting on thigh. Hence the distal tibia and fibula and proximal femur come next in importance to terminal phalanges and elbow.

With the union of these epiphyses, the animal has consolidated one end of each bony arm of its lever systems and finished the first phase of its epiphysial growth, leaving the other end to grow such that there may be a mathematical adjustment between the length of the limb, the size of the body and the manner of progression. This first phase is again divisible into a period of *'childhood or juvenility'* when epiphysunion of terminal phalanges and bones at elbow occurs, and a period called *'puberty'* when there is epiphysunion of long bones at 'hip' and 'ankle'. The epiphyses of metapodia (metacarpals and metatarsals) and other phalanges fuse either in the period of juvenility or puberty.

There may be a comparatively long pause during which general physical maturity is arrived at with commensurate increase in length and proportion of limb bones but with no attempt at fusion of their remaining ends. In some animals, e. g. rodents, the urge to completion of epiphysunion at knee and wrist is very slow and may not at all occur, e. g. at the wrist of captive rodents (Dawson).

The second phase or 'adolescence' is ushered in by fusion of the remaining long bone epiphyses round knee, wrist and shoulder without much concern about the sequence (Table VII).

The order of fusion as enunciated above holds true in terrestrial mammals of a *'generalised'* type that have no special adaptation to a particular habitat.

TABLE VII

Phases of Epiphysial Activity

First Phase (juvenility & puberty).		*Second Phase (adoleseence).*	
Terminal phalanges		**Proximal tibia**	... ... (knee)
Distal humerus ...	(elbow)	**Proximal fibula**	
Middle Phalanges		**Distal femur**	
Proximal Phalanges		**Dista radius**	... ... (wrist)
Proximal radius ...	(elbow)	**Distal ulna**	
Head femur ...	(hip)		
Metacarpals **Metatarsals** ...	(metapodia)	**Proximal humerus**	... ... (shoulder)
Distal tibia **Distal fibuln** ...	(ankle)		

TABLE VIII

Sequence of Ep. Union in limb-bones of Man (modified from Stevenson)

- Distal extremity, humerus
  - Medical epicondyle, humerus
- Head, radius
  - Olecranon, ulna
- Head, femur
  - Lesser and greater trochanters, femur
- Distal extremity, tibia and fibula
- Proximal extremity tibia
  - Proximal extremity, fibula
- Distal extremity, femur
- Distal extremities, radius and ulna
- Head, humerus
- Clavicle

Stevenson's table of epiphysial fusion (Table VIII) conforms generally to that given for generalized quadrupeds in Table VII. But when the condition is investigated in animals with specialised habits of progression, advancement in the sequence is observed on account of the mechanical necessity of accelerating the consolidation of ends of bones at some joints, and consequent relative retardation of others. Curiously enough, convergence of the schedule of fusion is seen in very divergent Orders of animals that have similar habits e. g. in the predatory Arctoidea and Viverridae (Order Carnivora) and Dasyuridae (Order Marsupialia), epiphyses of metapodia, distal tibia and fibula, and distal radius and ulna are accelerated and proximal femur is retarded.

In truly *aquatic animals*, the buoyancy of the water-medium of their habitat takes away from the epiphyses the urge for fusion, since they do not bear pressure in carrying the weight of the body. In Cetacea, the number of metacarpals tends to be reduced and phalanges increased ; epiphyses of the whole limb are in a state of degeneration though their number may be multiplied in the metacarpals and phalanges ; some epiphyses show lapsed union ; many epiphyses do not appear at all. The only constantly present synovial joint is at the shoulder, where proximal epiphysis of humerus goes through ossification comparable to land mammals. In animals of other Orders, epiphyses behave erratically.

For *aerial adaptation*, bats need to spread the wing or patagium wide to support the body in flight and also to flap them against wind-pressure. Epiphyses of manus, radius and ulna are retarded to allow the bones to grow long in order to increase the wing-spread. Epiphyses at shoulder and knee are accelerated because of the pressure exerted on them in dragging the patagium against wind.

Some Observations on Effect of Endocrine Organs on Skeletal Development and Epiphysial Fusion.

Gonads

1. Removal of testes or ovaries before puberty causes delay in union of epiphyses, causing the long bones to continue to increase in length. In man, radiographic study in such cases indicates that epiphys-union is retarded to later years of the second decade of life and may even go on to the third. In animals, some grow taller while others become shorter. The castrated oxen and goats of India are seen to become taller. Rats however become smaller. In our study on 30 gonadectomized rat skeletons and 31 of their litter-mate normal controls, we found that male castrates suffered in bone-length as compared with female castrates. The latter gained in body, bone and tail length. Regarding fusion of epiphyses, no significant change was noticed in the castrates.

2. Below is given a summary of the features observed by us in a 70 year old **eunuch skeleton** in Prof. Sydney Smith's Egyptian Collection (Edinburgh University).

(a) Lapsed Union is characteristically present in those epiphyses which are usually the last to fuse, e. g., in vertebral border of scapula, neural arches of vertebrae, crest of ilium, and sutures of skull and face bones.

(b) Faulty bone-formation near diaphysio-epiphysial junction, chiefly consisting of deficiency in compacta and partial non-union.

(c) Modelling of epiphysis and shaft of long bone is unaffected.

Removal of testes after puberty is said to cause no marked skeletal change. Since in the above skeleton, distal humerus escaped the stigma seen at other diaphysio-epiphysial planes, therefore the person must have been castrated after maturation of this epiphysis, i. e. after 14.0 to 14.11 yrs. Since proximal radius showed the stigma to a slight degree, so the castration might have been made between 15.0 and 15.11 years when this epiphysis was maturing.

In male hypogonadism, juvenile characteristics persist with extreme growth in arms and legs. The above skeleton presented very long limb bones. The following lengths and indices were found on the left side.

Humerus	38·30 cm.	Brachial index	79·89
Radius	28·20 cm.	Humero-femoral index	69·49
Femur	50·80 cm.	Crural index	87·11
Tibia	44·25 cm.	Inter-membral index	66·81

3. Ablation of **ovaries** gives results similar to above.

Thyroid

Lack of thyroid secretion retards bony growth. The skeleton becomes small and stunted with short arms and legs. Development and ossification are delayed, but fusion does ultimately take place. Skeletal differentiation in animals is normal in sequence but much slowed in rate (Boetigger and Osborn).

An Experimental Study.

Simpson and Liddel of Cornell University thyroidectomized 10 sheep and sent their skeletons with those of 3 normal animals to Prof. T. W. Todd of Western Reserve University (Todd, Todd and Todd). We were allowed to study the same material. The following are the observations :—

(a) Deficient growth and modelling of epiphysis. When ossification is completed, the epiphysis lacks character and is inadequate to cap the shaft.

(b) Defective development of age characters in both shaft and epiphysis.

(c) Defective growth in length of shafts due to slowing of rate of growth without extension of period of growth.

(d) No disturbance of bone-texture, weight, thickness or modelling of shaft.

(e) Suture-closure does not occur. There are irregular exuberances on shaft end resembling 'proud flesh' ; inturned, clawed epiphysial margins ; and a small poorly modelled ill-fitting epiphysis scarcely covering shaft end.

Thus the locus of damage to both growth and maturation is solely at the diaphysio-epiphysial junction. There is only a slowing of velocity of growth but no prohibition of developmental growth.

Application of Knowledge of Growth Studies in Cattle-breeding

1. The improvment of a sheep for mutton consists in a super-development of those parts which are largely composed of muscle. Early maturity is the first sign of this improvement (Hammond). In the skeleton this is expressed as an increase in the proportion of femur, which is important owing to the muscles surrounding it, to the cannon bones, which being surrounded by tendons have no meat value. Thyroidectomized sheep suffers from this point of view, because it tends to have a short femur and a long tibia and cannon, whereas a gonadectomized animal produces long arm and thigh bones and therefore gives more meat. Meat-producers in India are well aware of this and resort so much to the castration of their goats.

2. As the animal grows older, it requires more food for its maintenance. Hence gain in weight per unit of food consumed is less. Thyroidectomized animals are not economical from this point of view but the castrated ones are, as they grow for a longer period and fully utilize the food in increasing their size and body-weight.

3. Castration of farm animals facilitates their fattening. Overgrowth and flabbiness of musculature makes the meat tender and are desired features in animals that are meant to be used as food.

4. Thyroidectomized animals are dull and slow, castrated ones are active and docile. Hence castration before puberty is practised in India for producing draught animals.

Anterior Pituitary

When administered before union of epiphyses, it produces gigantism, more noticeable in females than in males. The skeleton becomes larger and heavier. The response is better in both sexes if gonads are simultaneously removed. It overstimulatss periosteal bone-growth and activity of normal ossification zones (Handlesman and Gordon). Hyperactivity of anterior pituitary in early life in man produces rapid skeletal growth and abnormal tallness due to delayed epiphysial closure (Lisser). Hyposecretion in early life produces dwarfs ; their skeleton is delicate, bones are small and typical childhood proportion of trunk and limb-lengths tend to be maintained throughout life. Complete ablation of anterior pituitary results in growth stasis and infantile condition- Dwarfs are thus produced.

Effect of Multiple Endrocrine Disturbances on Epiphysis of Man.

In defective hypophysial secretion with associated primary gonadal deficiency some long bone epiphyses never unite and are in a condition of 'lapsed union'. Radiographs in these cases show an epiphysial age much below the chronological age. Less pronounced cases may show more advanced epiphysial age but the lapsed diaphysio-epiphysial planes are not normal. They show the same heaped-up exuberant margins and surfaces as in experimental hyperthyroidism. A similar retardation is found in hypothyroidism and juvenile diabetes.

Epiphysial Growth and Fusion in Disease.

The exhaustive studies of Todd have shown that acute constitutional diseases in man retard the maturation of an ossific centre, but once the cause of retardation is removed the epiphysis marches normally to its fusion and the sequence-schedule is not disturbed. Similarly an acute disease occuring at the time when any epiphysis is due to unite may retard the fusion of that particular epiphysis without affecting the others. In cases of altered metabolism, there may be a general retardation of skeletal growth but there will be no specific onslaught on epiphysial growth and pattern. Similarly, disturbance in endocrine secretion, hereditary factors and environmental or nutritional changes may act on the epiphysial system *en bloc* without any particular bias.

In animals also the pattern of epiphysial union is not changed after gonadectomy, thyroidectomy or hypophysectomy. The phenomenon of lapsed union can be explained as the failure of a maximal stimulus to produce the minimal response in very tardy epiphyses, whether the stimulus is of internal origin, e.g. in endocrine disturbances, or of external origin, e.g. by loss of friction or pressure e.g. in aquatic animals.

B. Radiographic Studies of Pelvis.

Until recently even the most careful external measurements could not be relied upon to make a fairly accurate assessment of the pelvic architecture of woman (Thoms). Rohan Williams observed that clinial measurement of the true conjugate is either impossible or inaccurate unless there is gross pelvic contraction. For safe obstetrics, it is necessary that an idea of cephalo-pelvic disparity should be enquired into before the expected mother goes to the labour-room, in order that arrangements for operative interference, if any, may be planned ahead. Proper X-ray pelvimetry gives the best method for making accurate measurements of the dimensions and capacity of pelvis. Schumann (1936) measured the diameters of inlet of pelvis in 50 women directly at laparotomy, and found that the measurements did not vary more than 2 mm from the result obtained by X-ray pelvimetry. Stander reports that by combining clinical and X-ray pelvimetry fetal mortality has been reduced from 3·2% to 2·2%.

As early as 1946, we took up a radiographic study of the type of pelvis in adult Bengalee nulliparous women and confined our attention to finding out the different diameters of the *inlet only*. Between 1946-49 it was possible to conduct an examination on 82 selected healthy subjects. The technique adopted was that given by Thoms in 1938. Two skiagrams were taken for each subject, one for the superior strait called the 'AP' skiagram taken at a distance of 30″ from the X-ray tube and another, the 'Lateral' skiagram taken at a distance of 6 feet. Necessary corrections for parallax were made.

(In the following, CD means Conjugate or Antero-posterior Diameter and T.D. means Transverse Diameter).

Pelvic Index—is the proportion of the transverse to the conjugate diameter *expressed as a percentage*, i.e. Pelvic Index $= \frac{CD}{TD} \times 100$

Turner classifies pelvis into three types according to the pelvic index :—

(1) Platypellic—pelvic index less than 90.
(2) Mesatipellic—pelvic index more than 90 but less than 94·9.
(3) Dolichopellic—pelvic index more than 95.

Thoms' classification, now universally adopted, is as follows—

(1) Dolichopellic = CD is longer than TD.
(2) Mesatipellic = TD is equal to CD or not more than 1 cm longer.
(3) Brachypellic = TD is more than 1 cm longer than CD.
(4) Platypellic = TD is 3 cm longer than CD.

Below is given a comparative table (Table IX) giving the result of our finding against those of Thoms and Greulich.

TABLE IX

Type	104 white women mostly pupil nurses (Thoms & Greulich).	500 white clinic women (Thoms)	82 Bengalee women
1. Dolichopellic	37.5%	22.6%	24.4%
2. Mesatipellic	44.2%	46.6%	56.1%
Total of 1 & 2	81.7%	69.2%	80.5%
3. Brachypellic	18.2%	28.8%	17.1%
4. Platypellic	... ...	2.0%	2.4%
Total of 3 & 4	18.2%	30.8%	19.5%

The average measurements of the diameters as found in the different types of Bengalee female pelves are given in the following table (Table X)

TABLE X

Type	Conjugate Diameter	Transverse Diameter
Dolichopellic	11.50 cm.	10.00 cm.
Mesatipellic	10.75 ,,	11.00 ,,
Brachypellic	10.00 ,,	11.50 ,,
Platypellic	9.00 ,,	12.00 ,,

Our study was enlarged on 62 more cases between 1951 and 1953 and a *revised table* (Table XI) of distribution of the pelvic type is given below and compared with Thoms' series. Calculations have been done on 140 out of the 144 subjects studied.

TABLE XI

Type.	No. of Bengalee women.	Percentage.	No. of White women (Thoms)	Percentage.	No. of Negro women.	Percentage
Dolichopellic.	36	25.7	113	22.6	29	29.0
Mesatipellic.	69	49.3	233	46.6	43	43.0
Brachypellic.	32	23.0	144	28.8	25	25.0
Platypellic.	3	2.0	10	2.0	3	3.0

The following table (Table XII) gives the maximum, minimum and mean values of the diameters of pelvic inlet as seen in 140 subjects of the present work.

TABLE XII

	Conjugate Diameter			Transverse Diameter		
Type of Pelvis	Maximum	Minimum	Mean	Maximum	Minimum	Mean
Dolichopellic	12·88 cm.	9·17 cm.	11·56 cm.	12·2 cm.	9·4 cm.	11·18 cm.
Mesatipellic	12·88 ,,	9·35 ,,	10·78 ,,	13·54 ,,	9·2 ,,	11·3 ,,
Brachypellic	11·35 ,,	9·15 ,,	10·34 ,,	12·12 ,,	10·44 ,,	11·83 ,,
Platypellic	10·0 ,,	9·6 ,,	8·97 ,,	13· 0 ,,	12· 6 ,,	12·38 ,,

The slight alteration of values in our second series is due to calculations being done in a larger number of subjects. The table shows that the platypellic type of pelvis is the least frequent and the mesatipellic type occurs with the largest frequency in people of so widely divergent ethnic strains as the Bengalee, the American White and the American Negro.

Friends, there are so many aspects from which bones and bony cavities can be investigated in this country, that young anatomists in increasing numbers would be well-advised to take up studies on them. I have to utter only one word of warning to such prospective workers, and it is that they will have to have an abundant fund of patience and optimism and God will help them.

Ladies and gentlemen, as I feel that I have already exceeded my time-limit, I must now beg leave to resume my seat. But before I do so, let me express my grateful thanks to you, for giving me a patient hearing and all co-operation.

Jai Anatomy

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Printed at The Elite Press, 10, Haramohan Ghose Lane, Calcutta-10.

SECTION OF AGRICULTURAL SCIENCES

President :—DR. R. J. KALAMKAR, B.Sc., B.Ag., Ph.D. (Lond.), F.A.Sc.

PRESIDENTIAL ADDRESS

OUR PRODUCTIVE LANDS MUST BE SAVED

I am very grateful for the honour you have done me in electing me to preside at the meeting of the Agricultural Sciences Section of the 42nd Session of the Indian Science Congress.

I have chosen for my address a subject which I consider is of vital importance. The goals to which we as a nation are working are opportunity and security, a better way of life for all our citizens and of their children, which in the final analysis, are built on the permanent productivity of the land. A thriving agriculture is the basis of our national prosperity.

STATEMENT OF THE SUBJECT

I am conscious of the fact that the broader aspects of the subject have been previously discussed by Dr. Basu in his presidential address in 1951 but the best possible use of land and water for maximum permanent benefit of society is so obvious and urgent and so vital for survival of the country that restatement would not seem redundant. Such occasions help immensely to instill a spirit of conservation into the language and thinking of the country and thus develop enlightened public opinion in soil conservation and help in organising a dynamic national programme of research, education and technical assistance.

Almost every year the spectre of human misery and tragic waste visits us and we see natural resources destroyed by drought, flood and erosion. There are large regions of low and uncertain rainfall in India in which failure of crops is a regular feature. We have fresh in our minds the recent floods in the Uttar Pradesh, Bihar, Bengal and Assam and the terrible fate of Dibrugarh, one of the important tea towns. Considerable area of valuable land has been lost on account of erosion and deposition of sand. The damage caused by the floods is a severe blow to the economic life of the whole country. It is a national calamity.

CAUSES AND TYPES OF EROSION

Productive land is a natural resource that we cannot get along without. That we have been wasteful in the use of this resource, there is not the least doubt. Over large areas in the hilly and mountainous regions of the country, the protective cover of the forests has been destroyed. The causes of the destruction are varied. Over-grazing by cattle, sheep and goats, is one of the major causes. Extensive disforestation due to demands of fuel and timber and to make room for cultivation for the expanding population are other important factors. In some areas, as in the parts of Assam, Bihar and Orissa, shifting cultivation which is practised by the tribal people is the principal cause of destruction of forests. As a result of large destruction of forests and other natural vegetation, large areas in all parts of the country are suffering from erosion.

Sheet erosion causes enormous loss to agriculture by washing off the top layers of the soil and reducing the productivity of land, while gully erosion ruins the acreage of productive land. Of the two types of erosion, gully erosion is the more spectacular type while sheet erosion is the more dangerous type, creeping on unnoticed. The destructive action due to sheet erosion may not be felt in the first few years but when neglected usually ends in gully erosion.

Erosion is taking a heavy toll of the soil every year. The extent of its ravages can be gauged from the vast tracts of land that have gone out of cultivation and others whose potential fertility has been reduced to a very low level. There is hardly any State in India which is free from the menace of erosion. The kind of erosion and the extent of damage, however, varies in different regions.

EXAMPLES OF SOIL EROSION

Perhaps, the most striking example of soil erosion in India is to be found along the Jamuna and the Chamble rivers in Uttar Pradesh and Madhya Bharat. Here erosion has been caused by the gullies eating back into the fertile gangetic plain. The gullies are constantly extending their perimeter thereby adding to the devastation. These areas are still inhabited by the people who in trying to eke out a bare existence on the ruined land contribute to its further deterioration.

The ravines of Jhelum, the *Kotar* lands of Gujerat, the *Chos* and the land slides in the Hoshiarpur Shiwaliks are clear examples of havoc wrought by erosion. In 1852, the *Chos* (torrents of water heavily charged with sand and silt in suspension) in Hoshiarpur, covered an area of 48,206 acres which increased to 80,057 acres in 1884, 94,236 acres in 1897 and in 1936 it was estimated to cover an area of over 1·5 lakhs acres. Puri has observed that apart from such variable factors as disforestation, excessive grazing and burning of vegetation, high rainfall and steep topography, the Hoshiarpur Shiwalik hills are predisposed to erosion and land slips on their southern dip slopes on account of their structure, composition of the rock and the inherent geological activity in northern India. Similarly, in the entire area of Chhota Nagpur plateau, the gully heads as analysed from the old survey maps and more recent maps made from air photos, show that the gully heads have been making an alarming headway at the rate of 6 feet a year. Besides, there is a dangerous feature of increasing of overall perimeter of rotting banks by the rapid widening of the trough along with each recently cut gully which threatens to destroy a considerable portion of area under upland cultivation. This is particularly insidious in those areas where a calcarious sub-soil is decaying faster than the top crust and forms pot holes many yards back from the working head of the active gully.

Bad effects of misuse of land are illustrated in the Nilgiri hills, Madras where potato cultivation is done on steep slopes sometimes exceeding over 60 per cent and in the Khasi and Jaintia hills of Assam where potatoes are grown by a short cycle of Jhuming which leads to heavy soil losses.

The problem of erosion and moisture conservation is of very great importance in the large regions of low and uncertain rainfall in India which occupy longitudinally the central core of the country, viz., the Rohtak area of the Punjab, Madhya Bharat and Bombay-Hyderabad-Madras-Deccan area. These regions are characterised by scanty, ill distributed and highly erosive rains, undulating topography, high wind velocity and shallow depth in general. The period of heavy rains from August to October is a critical period of erosion. The soil loss from poor fields is about 50 tons annually and may be as high as 150 tons in a year.

WIND EROSION

Wind erosion has also been responsible for the loss of valuable top soil in many areas. Wherever soils without a cover of vegetation in a dry state are exposed to high winds, we have wind erosion. Halting the march of the desert is one of the vital and outstanding problems facing India today. The present Rajasthan desert is mainly a blow in sand. There is evidence to show that the age of the present Rajputana desert is less than that of the Christian era and this area was once a fertile and flourishing land irrigated by a number of rivers. The ancient towns of Mohenjodaro and Harappa which are now buried in sand had been once flourishing towns situated on the banks of large rivers and are now a standing evidence of the ravages of the encroaching desert. Incontrovertible evidence has been adduced during recent years demonstrating the fact that the Rajasthan desert is on the march which threatens to engulf the fertile alluvium of the Indo-Gangetic Plain. It has been estimated that it has been spreading outwards in a great convex arch from Bhawalpur, Firozepur, Patiala and Agra towards Aligarh at the rate of about a mile per year during the last 50 years. In South India as a whole wind erosion is not as extensive as water erosion. Along rivers like the Hageri and Pennar, in the ceded districts, sand dunes are common. During summer when the river is dry, high south-west monsoon winds lift up the sand and carry it along the great distance depositing it on the black soils and render the latter unfit for cultivation in the course of some years. If this drift is allowed to go on without hindrance much of the cultivated land will get covered up annually. Extreme example of sand driven from the coast is to be found in Saurashtra where the shores of the sea on which once international ports flourished are now strewn with advancing sand dunes.

OTHER TYPES OF EROSION

In addition to the erosion from cultivated fields, pastures and waste lands, a large amount of roadside erosion also takes place due to the defective highway engineering by way of formation of borrow pits or fresh earth cutting and absence of adequate vegetative cover for protecting the shoulders and the roadside drainage ditches from erosion. Proper highway engineering should include proper sectioning not only of the road fill but also of the trench ditches along side the road and a proper protection of the entire section by means of vegetation cover such as of grass.

Defective drainage and water logged conditions also cause appreciable areas going out of cultivation every year and in an indirect manner also increase the erosion hazard.

EROSION IS MAN MADE

From what has been said above, it can readily be seen that soil erosion is not only a natural phenomena. It is also man made. The methods of exploiting natural resources have been defective in the past and they continue to be so resulting in soil erosion. This results in gradual loss of soil fertility, covering of considerable area of fertile land in the valleys and plains with sterile sand, fall in ground water level and in some cases drying up of wells, silting up of rivers, lakes and reservoirs and increasing, frequent and severe floods in the rivers and gradual dessication of lands close to the desert and increasing aridity of the desert. The damage caused by this to the Indian economy every year in the way of reduced productivity in agriculture and physical destruction of life and property through floods etc. is alarming and the very existence of agriculture and settlement in many areas is threatened by erosion and other processes.

LAND UTILIZATION AND CROP PATTERN.

Closely allied with the problem of soil erosion is the problem of land utilisation. The total geographical area of the country is 811 million acres, but land use statistics are available for only about 615 million acres. The bulk of the 196 million acres for which land utilisation statistics are not available consists of mountains, deserts and inaccessible forests. The area of forests for the Indian Union as a whole is estimated at 147 million acres. The gross cropped area is about 317 million acres of which about 35½ million acres grow more than one crop. The food crops cover about 78 per cent of the cropped area of which cereals alone occupy 61 per cent and gram and other pulses 15 per cent and commercial crops which produce raw material for industry account for 17 per cent. Current fallows occupy about 58 million acres and from out of 98 million acres of uncultivated land excluding current fallows, culturable area is estimated at about 11½ million acres.

RECLAMATION OF WASTE LANDS AND LAND GONE OUT OF CULTIVATION

The chief reasons for leaving such lands uncultivated are :—

(1) Deep rooted grasses like kans and other weeds.
(2) Unhealthy conditions chiefly due to malaria.
(3) Lack of drainage.
(4) Low fertility of the soil.
(5) Lack of water supply.
(6) Salinity and alkalinity.
(7) Damage by wild animals.

The cultivable wastes are covered either with a scrub jungle or with deep rooted weeds like kans. Kalamkar and Ekbote estimated that in the worst affected kans lands 115 maunds of fresh roots in one foot depth of soil per acre were noticed. The weed infested areas are spreading out every year and these are either entirely out of cultivation or are producing progressively less and less according to the degree of infestation. It is estimated that 10 million acres of such lands have gone out of cultivation in States like Madhya Pradesh, Madhya Bharat, Bhopal, Vindhya Pradesh, Uttar Pradesh and East Punjab.

Similarly, large areas are affected by Usar. It is estimated that in Uttar Pradesh alone over 2 million acres are so affected. In the Bombay Deccan, out of the total irrigated area of 75,000 acres, ⅓rd is more or less affected by salts.

The study of the records of the past forty years reveals that in spite of increasing pressure of population very little extension of cultivation of waste lands has taken place during the period. This seems to indicate that the available cultivable waste does not generally lend itself to reclamation within the present resources of our farmers. Small areas may be added here and there but for any schemes of materially increasing the area under cultivation, reclamation and rehabilitation work has to be undertaken on an organised scale. Only the State efforts or State sponsored efforts can hope to do this. The First Five Year Plan envisages the reclamation of 7·4 million acres of land. Of this, the Central Tractor Organisation is expected to reclaim 1·4 million acres and the State Tractor Organisations 1·2 million acres. Reclamation by farmers with the assistance of State Governments and measures to bring recent fallows back into cultivation are expected to result in the development of a total area of 4·8 million acres. So far, the Central Tractor Organisation has carried out kans clearance in over 1·22 million acres of which Madhya Pradesh alone has contributed about 0·42 million acres. In Nainital Tarai areas of Uttar Pradesh about 43,300 acres have also been tree-felled and have been handed over by the Central Tractor Organisation after ploughing and harrowing for the raising of crops.

NEED FOR INCREASING PER ACRE YIELDS THROUGH IMPROVED TECHNIQUES OF LAND UTILIZATION

While extension of cultivation can be an important factor in stepping up agricultural production over a period of time, for meeting the immediate needs of the nation reliance has to be placed mainly on increasing the production from the existing area by increasing per acre yields through improved techniques of land utilisation. In the First Five Year Plan, from out of the net food production target of 7·6 million tons, a little over 1·5 million tons alone is aimed at through land reclamation and development while the bulk of it is through irrigation—major and minor—and the rest through the use of improved seeds, manures and fertilizers. The problem of soil conservation assumes a vital significance in the arable lands due to their vast extent.

CENTRAL SOIL CONSERVATION BOARD ESTABLISHED

The establishment of the Central Soil Conservation Board in India as per recommendations of the Planning Commission augurs well for the future of conservation in India. It is, however, necessary that proper and effective co-ordination should be maintained with such bodies as the Central Water and Power Commission and the Flood Control Board. The main functions of the Board will be to organise, co-ordinate and initiate research in soil conservation, to assist States and river valley projects in drawing up their soil conservation schemes and in enactment of legislation required for the purpose, to act as a clearing house of information, arrange for training of technical personnel and recommend financial assistance for schemes of States and river valley projects on an approved basis which would include both research, demonstration and extension.

The Central Soil Conservation Board has already sanctioned schemes for the establishment of Soil Conservation Research Stations in different parts of the country on a regional basis. Training and demonstration will be linked up with research at these centres. The centres are :—

(1) Dehradun with sub-centre at Chandigarh for research on foothill erosion, and *Chos* control.

(2) Kota with sub-centre in Kotar land of Gujerat for research on riverine areas in the alluvium.

(3) Jodhpur for desert afforestation research which was already in existence.
(4) Shabibnagar in Hyderabad with sub-station at Bidar for soils derived from rocks of Archeon origin obtaining in the Deccan plateau.
(5) Bellary (Mysore) representing the black soil area in the Deccan.
(6) Ootakmund in the Nilgiris where the problem of erosion is very different from that of the Himalayas.

There is already a Research Centre at Hazaribagh of the Damodar Valley Corporation and proposals are under way to tackle the problem on a much wider front so as to be useful for river valley projects in the country as a whole instead of concentrating on the local immediate problems as at present through the joint efforts of the Central Soil Conservation Board and the Damodar Valley Corporation. Similarly, there is already a Soil Conservation Research Station at Sholapur run by the Bombay State and the question regarding integration of its working with the Central Soil Conservation Board is under consideration. Soil Conservation Research Stations, one in each of the Cotton and Wheat Zones, have also been established in Madhya Pradesh.

The establishment of this chain of research stations located in typical areas of widespread erosion will serve to collect data on soils, land use, rainfall, run off, soil wash under different conditions and effectiveness of various types of vegetation cover in arresting soil erosion. They will serve as centres for demonstration of improved land use and soil conservation practices to cultivators in their respective areas.

STATE LAND UTILIZATION AND SOIL CONSERVATION BOARDS

The Planning Commission has recommended a Land Utilization and Soil Conservation Board in every State for formulation and implementation of suitable policies and programmes of soil conservation. So far only 17 States have undertaken suitable legislation for soil conservation. Such legislation is useful for compelling the minority to fall in line with the wishes of the majority who desire to take up land improvement programmes.

INFORMATION AND EDUCATION

Though legislation will be necessary to strengthen the hands of the Soil Conservation Service, the programmes for soil conservation essentially call for enlisting the spontaneous and willing co-operation of the villagers. The significance of this point cannot be too much emphasised. The job is one of education and can be handled in two ways :—

(1) Publicity and propaganda through audio-visible aids.
and (2) Demonstrations.

The first phase can be taken up immediately. For this purpose all the necessary basic information can be compiled from existing publications, local and foreign experience and research data available from research institutes. The Central Soil Conservation Board needs to be considerably strengthened in this respect. This calls for establishing a well equipped library and information and publicity section. Similar action will have to be taken by the respective State Governments. In this connection, mention must be made of the Soil Conservation Society of India which is doing valuable work through its journal. One of the main objects of the Society is the promotion of knowledge on soil and water conservation and the development of the public opinion.

Dissemination of conservation ideas could also be carried through the Extension Training Centres for Village Level Workers and supervisory staff in the Community Projects and the National Extension Service Blocks and other officials of the Revenue, Co-operative and Rural Development Departments, Village Priests, etc.

An equally important step to make every body erosion conscious is to start also from the schools where the fundamentals of soil conservation should be taught as a part of the curricula thereby creating a definite knowledge and wish for soil conservation. The intention is not to treat soil conservation as a separate subject but to integrate the simple principles of sound land use in other scientific subjects so as to make the future generations conservation minded.

Similarly, in the Agriculture Colleges and Universities, there should be diploma and degree courses in soil conservation.

Observation of Soil Conservation Days on suitable occasions by putting in selected areas various soil conservation practices through participation of farmers on a co-operative basis and organising N. C. C. Camps for such purposes will also help in this direction.

PILOT DEMONSTRATION PROJECTS

The second phase, demonstration, will bear fruitful results only after some years. It involves trial in the different problem areas of the soil and water conservation practices which have proved successful in improving soil productivity and also experimentation with the methods which have proved successful in foreign countries. So far as villagers are concerned, education through publicity, lectures, etc. can create a favourable background, but real conviction can come to them only from seeing the actual results in demonstrations.

The Central Soil Conservation Board has already invited from the States schemes for pilot or demonstration projects in an accessible area of the State covering a complete water shade of 2,000 to 5,000 acres of land for which financial assistance from the Central Soil Conservation Board will be forthcoming. Not much progress has however been made so far in this direction. To begin with, substantial subsidies will have to be given by the Centre to organise such projects.

TRAINING OF PERSONNEL

One of the great bottlenecks is the lack of trained personnel, but with facilities which are being made available by the Central Soil Conservation Board at its research centres, this difficulty will be remvoed to a limited extent. Similar training facilities are also being extended at Sholapur by the Bombay State, but to meet vast demand that will arise, there should be training centres for soil conservation for different categories of personnel in every State and soil conservation service created on the U.S.A. model for helping the farmers in farm planning.

RECONNAISSANCE EROSION SURVEY

Steps for the control of erosion and conservation have been taken for a number of years in certain States like the Punjab and the Bombay State. More recently, the Soil Conservation work has been taken up in several other States also, but there has been no country-wide effort in this direction so far and even in States where the work has been going on it has been only on a very limited scale. The programme as provided in the First Five Year Plan though small compared to the magnitude of the problem, marks the beginning of a countrywide effort to tackle it. A sum of Rs. 2 crores was provided by the Central Government separately for soil conservation work during the period of the plan, but when the plan was revised recently, it was reduced to Rs. 1 crore as hardly any expenditure was incurred during the first half of the plan period.

The first thing that needs to be done in tackling the problem is, as recommended by the Planning Commission, to conduct a rapid survey of the reconnaissance type by which the major erosion affected areas are demarcated and the type and the degree of erosion in each area together with the broad measures needed for tackling the erosion problem can be determined. Such a survey should be completed in a specific period of say two or three years.

The technique of such survey should be standardized by the Central Soil Conservation Board so that the results obtained from the different States are comparable. It is desirable that such surveys should be undertaken by the Central Soil Conservation Board itself.

SOIL AND LAND UTILIZATION SURVEY

Similarly lack of Soil and Land utilization surveys is one of the major handicaps in the execution of a long term programme of Soil Conservation. In India, Soil Conservation Survey has not yet been carried out on a systematic and planned basis excepting some surveys of local interest. Since 1945, such conservation surveys have been undertaken by the Soil Erosion Section of the Land Improvement Research Project of the Bombay State. Another important centre in India where soil conservation survey and preparation of land use have been undertaken systematically is the Damodar Valley Corporation. This work needs to be considerably intensified.

Apart from the broad aspects of land utilization survey the soils require to be surveyed in greater detail with a view to recognise the agricultural capacities and potentialities of each soil type of the country. This will entail long term investigations of soil and crop relationships. A survey of the soils of India along lines envisaged above has been attempted, but only recently. A lot of valuable information is, however, available from old records such as that of land settlement and geological survey and Government Agricultural Departments. Classification of soils has been attempted by some workers on the basis of their nitrogen, phosphorus and potassium, lime content and the mechanical composition of surface soils. Such classifications have some agronomic value but have many limitations. A comprehensive attempt was made to collect and collate this data under the auspices of the All India Soil Survey Scheme financed by the Indian Council of Agricultural Research and Soil Maps of India and States prepared on the basis of this knowledge but they are not adequate enough for land use planning.

The soil survey work has now been taken up in some of the Community Project areas of the country with the aid of the T.C.M. and a cartographic laboratory is being set up in the Indian Agricultural Research Institute. All India Soil Survey Scheme has also been prepared for inclusion in the Second Five Year Plan. The objective of the scheme is to classify and map out kinds of soils, giving them common nomenclature so that proper research and management and use of soil resources could be planned and results of research applied to individual fields without undertaking detailed analysis in each case. The Central Soil Conservation Board will function as a co-ordinating agency for soil survey.

NEED FOR PERFECTING TECHNIQUES OF SOIL CONSERVATION

Soil and land utilization survey would furnish basic data necessary for indicating a larger and more comprehensive programme commensurate with the magnitude of the problem in subsequent years. The problem of soil conservation has to be viewed as a multi-purpose project and has to be tackled on a water shade basis. However, research is needed pertaining to the various aspects of soil conservation. Even the basic techniques of soil conservation, viz., construction of bunds and terraces although old are not adequately understood. Research is needed to study :—

(1) The types of terraces suitable for different soil climate zones.
(2) Spacing or vertical interval between the terraces.
(3) Determination of terrace grades.
(4) Type of cross section of the bunds.
(5) Means of stabilisation of terraces both by mechanical and vegetative methods.

Research work on characteristics of the soil such as texture, its depth and permeability and analysis of the rainfall pattern need to be intensified before a suitable land use plan can be successfully evolved. Climate and soil conditions affect crop production and any system of crop management must take cognisance of these factors. Failure of a measure undertaken on the advice of scientist leads not only to the rejection of the advice in that particular respect but also shatters the belief in scientific methods. Definite conclusions leading to recommendations should be arrived at only after proper research.

STUDIES OF RUN OFF, SOIL LOSSES AND ERODIBILITY OF SOILS

Soil erosion studies in India are of comparatively recent origin. No systematic quantitative measurements of run off and erosion were made in India until the initiation of the co-ordinated dry farming schemes in 1933 when a chain of research stations was established in Solapur, in Bijapur (1936) and Hageri (1937) in the dry zone of Peninsular India representing the Black Soils derived from Besalt. The average run off as percentage of total annual rainfall is 18, 22 and 20 and the average soil loss, in tons per acre per year is 44, 9 and 6 respectively at the above stations on about 1·25 per cent slope. The studies are also in progress in red and laterite soils derived from Granite at Nanjnad (Madras) and from old alluvium at Shantiniketan (West Bengal) and at Nagpur representing the Black Cotton Soils. The chain of research stations to be established under the Central Soil Conservation Board will also furnish valuable data on run off and Soil loss.

Plant cover and any litter on the surface of the soil protect it from the beating action of rain drops. Rain drops fall with a lot of force. When the rain drops fall at the rate of 20 miles per hour which is not unusual, 2″ rain exerts enough energy when it hits the soil, to lift a 7″ layer of soil 3 ft. high. Growing in Groundnuts, Dolichos biflorus, Phaseolus aconitifolius, Soyabean, Phaseolus mungo during the khariff season have been found to be very effective in the Bombay Deccan in substantially reducing erosion and to a certain extent run off. For these crops, erosion losses vary from less than a ton to a little over 2 tons. The cultivation of juar which is the common practice in this tract shows an enormous loss of soil viz., 7″ of top soil in 27 years.

Along with the losses of run off water and soil, considerable amounts of plant nutrients are removed when the lands are put under cereal crops like Juar. Losses of plant nutrients due to erosion in lbs. per acre were estimated at Sholapur as N 127, P_2O_5 130, K_2O 1272 and CaO 8521 lbs. Such a stupendous drain cannot be fully made good even at great cost. The only solution is to resort to soil conservation measures to check loss of soil run off and plant nutrients.

Interesting information on the change in the depth of arable soil under type of cropping system prevalent in the cotton districts of Berar has been obtained in connection with the scheme of crop cutting experiments on cotton under the auspices of the Indian Central Cotton Committee. The fields under the cotton survey for a period of 3 years from 1944-45 to 1946-47 were classed according to the old depth data recorded in 1872 Settlement as well as the depths actually measured during the survey. The three depth classes adopted were—(i) 31″ and above, (ii) 15″ to 30″ and (iii) below 15″. It was observed that during the course of about 75 years, the increase in the number of fields in the depth class below 15″ was 54 per cent in Akola while it was only 16 and 8 per cent respectively in Yeotmal and Buldana districts. Erosion has been most noticeable in Akola district and least in Buldana.

Soil depth and yield relationship were also investigated. The yields were in general found to decrease with decrease in top soil. As against the yields of seed cotton of 215, 255 and 270 lbs. per acre in Akola, Buldana and Yeotmal for deep soils, the yields for shallow soils were 125, 134 and 133 lbs. respectively.

While the degree of erosion is dependent along with other factors, on the type of soil, slope per cent and the intensity of rainfall, it also essentially depends upon the cropping system in vogue. Investigation into the causes of these wide differences would materially help to find out factors responsible for erosion or otherwise.

CROP ROTATIONS

Proper land utilization calls for proper understanding of classification, use and treatment of land according to its capabilities. The inherent productive capability of the soil for producing good and large yields depends on the degree of success or failure of soil management practices to maintain (i) soil organic matter, (ii) plant nutrient supply, (iii) Soil structure—physical condition of the soil ; and (iv) depth of arable soil.

The question of soil depth has already been discussed above. The importance of crop rotations in general maintenance of soil fertility is well-known. Loss of organic matter and nutrient elements and deterioration in the physical properties or tilth of soil are a few of the several ways in which soil may deteriorate under cropping. Continuous cropping depletes the soil organic matter. The choice of crops in a rotation has to be based on the land use capabilities. Some useful work in this direction has already been done for crop rotations with particular reference to Sugarcane in the Bombay State by Basu and similar work on some of the Uttar Pradesh soils has been done by Mukerjee and Agrawal.

Crop rotations under dry land farming conditions have to be basically different from rotations for more humid areas as apart from the maintenance of soil fertility, more stress has to be laid on moisture conservation in the soil. A system of fallowing has to be introduced to achieve this end. The experiments conducted at the dry farming research stations at Sholapur, Bijapur, Raichur and Hageri show that the practice of fallowing of a small part of the holding systematically every year and of growing a crop in alternate years would secure a crop on the fallow land even in a year of drought. In good seasons, appreciably increased yields are obtainable on fallow land. These would largely compensate the losses of crop incurred in a year of fallow. Fallowing, however, can be a success only on soils which have sufficient depth to conserve the rainfall of one season and carry over the soil moisture to the next season. In some cases it has been observed that those rotations which do not include an area of fallow have become increasingly infested with weeds.

IMPORTANCE OF LEGUMES

The growing of legumes in a cropping system is widely recognised as useful in the maintenance of fertility ; but information in respect of legumes which will be most suitable for this purpose in the different tracts is meagre. There is ample scope for finding out or evolving suitable legumes for different tracts. Balasubrahmanyan, and Sunderam have reviewed the experiments conducted with legumes preceding cotton in Madras State and have pointed out the suitability or otherwise of different legumes for rotation or mixed cropping for different tracts of the State. Results obtained recently in cotton growing districts of Berar and Hyderabad have indicated a beneficial effect of including groundnut into normal cotton-junar rotation. In various parts of northern India, striking increases have been obtained in the yield of cotton which follow a phosphate manured crop of Berseem. Experiments have been conducted to show the importance of a kharif pulse like Arhar or a rabi pulse like Gram for the maintenance of fertility of the soil in the Wheat tracts of Madhya Pradesh. Some information is also available as regards recuperative power of different kharif and rabi legumes, e.g. from sand cultural experiments conducted by Bal, he observed that in respect of recuperative powers the kharif legumes tried might be placed in the order Arhar, Sann, Groundnut, Mung, Urid and in case of rabi legumes—Lakhori, Gram, Lakh and Masur.

Considerable leeway has, however, yet to be made to evolve suitable rotations on the basis of land use capability which takes into consideration information regarding soil type, slope, character, degree of erosion and other physical factors and land conditions.

CROP MIXTURES

The mixture of crops which includes some leguminous crops takes a place of rotation in many places. This also acts as an insurance against weather. Suitable crops to be grown in a mixture and their proportions need to be worked out for different soils and climatic conditions.

CROP SEQUENCE

More scientific work is needed in regard to the effect of crops on those which follow. Some of the work done in Madras shows that when cotton followed Juar, the yield of cotton was less than that when cotton followed Bajra. Similarly adverse effect of Maize or Juar on the yield of Wheat following them when compared with the yield of Wheat after fallow has been observed at the Indian Agricultural Research Institute, New Delhi.

Phosphatic manuring of legumes also requires detailed investigations. Phosphatic manuring of berseem has been found to build up the soil fertility. Some of the legumes have not responded to phosphatic manuring and in building up the soil fertility.

Investigations into biological processes particularly activities of fixing organisms, the effects of legumes on the moisture and the nitrogen status of the soils and the availability of mineral nutrients especially phosphate in different soils would be of great value for a better understanding of the problems of soil fertility maintenance.

STRIP CROPPING

One of the important practices to control erosion and thereby maintain the fertility of soils is that of strip cropping on the contour which is a modified form of crop rotation. Some useful work has been done in India particularly in the Bombay State but considerable ground has yet to be covered in respect of determining suitable crops for different regions, the width of strips and the seed rate in order to secure best results for erosion control under different slopes and types of soil.

GRASSES IN ROTATION

One very important point is the importance of grasses in rotation. It is likely to play an important role in the Agriculture of our country which would involve change in the type of farming. Many of the lands would be better suited for this. There is urgent need for production in milk and milk products which will be possible if grasses and fodder legumes are fitted into the rotation. Scope for this, perhaps, appears to lie both under irrigated and dry land farming. Much of the benefit from growing fodder crops is due to the influence they have upon aggregation or binding together of soil particles. A high degree of aggregation promotes more rapid infiltration, more air movement within the soil, prevents excessive run off and less erosion occurs.

ROTATIONS UNDER IRRIGATED CONDITIONS

There is need for evolving suitable crop rotations in Agriculture under irrigated conditions particularly in view of the irrigation facilites which would be available under the multi-purpose river valley projects. This would also involve, as is common with rotations under dry land conditions, investigations into the manuring of crops in a rotation to build up soil fertility.

ORGANIC AND INORGANIC FERTILISERS

The value of manures and fertilizers in increasing yields of crops needs no emphasis. Crops differ in their nutrient requirements. Some information is available in respect of effect of nitrogen, phosphate and potash applied through bulky organic manures or fertilizers. Much leeway has, however, to be made to determine the doses, form, time of application and method of application and their combination under different soil and climatic conditions. Soil fertility investigations under the T.C.M. Programme which involves conduct of simple experiments on a large scale on the cultivator's fields and of complex experiments at a few selected Centres will help a great deal towards finding out the nutrient requirements of different soil types on the basis of which manuring schedules could be worked out.

Very little work is done in India on a long term aspect of assessing the value of organic manures. Green manuring and phosphatic manuring of legumes need to be investigated with a view to utilise the land properly. The important problem regarding green manuring is the question of introducing it into the cropping systems with necessary modifications in purely rainfed areas without losing the main crops. Some experiments in respect of growing green manure crops in the standing crops of cotton and rice are in progress in Madhya Pradesh.

TRACE ELEMENTS

Besides investigations regarding the general manurial requirements of crops as referred to above, much work is needed on other soils ameliorants including trace elements. Special emphasis needs to be laid on trace elements. With the facilities available under the T.C.M. Programme, it is hoped considerable headway will be made in this direction.

CULTURAL PRACTICES

For proper land use, apart from devising suitable protective soil building crop rotations and their manuring, there is also need for resorting to suitable tillage or cultural methods. In this category may be included such items as depth of ploughing, repeated shallow cultivation during the monsoon period to conserve water, rates, times and methods of seeding, sub-surface tillage and adopting these practices on the contour.

In short agronomic science and practice has much to contribute towards better land use and conservation and a dynamic programme of research needs to be intensified for developing field techniques to take up Soil Conservation measures on a countrywide scale.

CONCLUSION

To conclude the future of our country and its teeming millions depend to a large extent on the conservation of our land resources and a maintenance of a permanently productive agriculture through proper use and treatment of land. The need for soil and water conservation will, therefore, be all the greater in future for supporting a growing population at a reasonable standard of living and to meet the increasing demand of our industries of raw material. Execution of a long term programme of Soil Conservation on a countrywide scale embraces Soil and Land utilization surveys, planning and practices, dynamic national programme of research, education including development of enlightened public opinion, training of personnel, land policy and institution of an efficient organization. It is a challenge to the Scientists to perfect techniques of Soil Conservation which will prove suitable for small holdings and limited resources of the Indian cultivators.

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SECTION OF PHYSIOLOGY

President :—N. N. Das, M.Sc., M.B.

PRESIDENTIAL ADDRESS

THE ROLE OF BIO-ELECTRIC POTENTIALS IN THE LIVING SYSTEM

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May I venture to state, even though inadequately, my indebtedness to you for having conferred upon me the signal honour of presiding over the Physiology Section of the 42nd session of the Indian Science Congress. This is a rare privilege for which I am sincerely grateful. But with this privilege goes the incumbent responsibility of executing the traditional functions of a president, among others perhaps the most onerous being the delivery of a presidential address. The onus of this particular function seems to centre around the choice of a suitable topic for the occasion, for I was profoundly conscious at the time of preparing this address of the galaxy of distinguished scientists whom I was to address. I shall confidently assume your sympathy for in it lies my strength.

Thirty years is a considerable portion of a man's life. I feel happy to state that for the past 30 years I was actively engaged in electrophysiological studies. During this time I had the good fortune to work with Sir J. C. Bose and Sir Ramnath Chopra on various aspects of the subject in both plants and animals. I have chosen for my address this particular subject not only for its own sake, but also with the fond realization that my guides, Sir J. C. Bose and Sir Ramnath Chopra, would have been delighted with my choice.

The topic of my address is "The Role of Bio-electric Potentials in the Living System". In the past, this subject did not occupy a significant position in the mosaic of physiological knowledge. However, with the advent of highly precise recording instruments with thermionic valves, it has been possible to demonstrate and record potentials from living tissues in rest and activity. Results obtained with such instruments necessitated an entire reorientation of the status of the subject and has projected it into a new light, and I may venture to assert that this has opened avenues with vast possibilities in the way of experimental research. I wish to present an account of the salient features of this young subject.

INTRODUCTION

In the process of evolution, the complexity of the living organism appears to have gradually increased : the simple unicellular organism was transformed into a complex multicellular one. This transformation necessitated that the latter had to undergo some kind of adaptation, in terms of its structural change, without which it could not have survived. The simple unicellular organism was intimately in contact with its environment and therefore needed no elaborate arrangement to balance its relations with its environment. On the other hand, however, in the complex multicellular organism, the greater part of its cell aggregation was far removed from the external environment. These organisms therefore required some arrangement by means of which they could be made sensible to changes in the environment. To control this sensibility, and to link it with impressions from the outside received by the eye and other sense organs previously, they became possessed of a complicated nervous system and an exceptionally complicated brain.

A vitalistic attitude towards the mechanism of nervous activity is in my opinion not fruitful. On the contrary, bio-electric phenomena are a purely physical phenomenon and lend themselves to a quantitative consideration. Let me illustrate this point. I see an approaching vehicle. I instantaneously become aware of the consequences of being run over. I leap out of its way. Now, all the factors involved in this series of activities are physical and, therefore, measurable from a theoretical standpoint at least, though, in practice, several difficulties may arise. The light reflected by the vehicle enters the eye and is focussed on the retina, where the light energy, transformed into electrical energy, passes as such along nervous pathways to the visual centres in the brain and I *see*. From the visual centres the electrical energy is retransmitted to the neighbouring visuo-psychic centre, where, as a result of association with stored images and experiences, I become aware of the consequences of being run over. The brain then sends a series of "messages" in the form of electrical nerve-energy to relevent parts of the body declaring a "state of emergency" and, as a result of the co-ordinated activity of all the informed parts, I am removed from danger. Thus it becomes evident that these bio-electric potentials of the brain and nervous pathways are of fundamental importance to the survival of the organism. There are more than a billion neurons (nerve units) in the human brain, and they are interconnected so that each cell is rarely active without influencing others. The essential activity seems to consist in a sudden change in the cell surface which allows a momentary escape of some of the molecules. This surface change may be repeated at very short intervals so that the cell may become active and inactive as often as fifty times a second, and each time it becomes active an impulse will pass out from the cell to its neighbour or farther afield to other parts of the nervous system.

HISTORICAL

If we look back into the past, the importance of the nervous system in living organisms was recognised by the ancient sages of India. They could realise by certain practices the structure of the nerve centres and spinal cord and they mentioned in the Shastras about the *Sat-Chakra*, where the brain is represented by thousands of petals, and lower centres are similarly represented by smaller groups of cells. It has also been described in the Bhagbat Geeta that the human nervous system is like an uprooted and inverted tree, where the brain is compared with the mass of roots, and the downward branches of the tree with the nerves, dividing as they proceed away from the roots. To us moderns, who have a vast fund of knowledge to fall back upon, this concept may seem too simple and unworthy of much credit but we should think of it as representing the heightened consciousness of man almost 3500 years ago. It has been described that the spinal cord is divided into three pathways: the *Ida*, *Pingala*, and *Susmna*. The practice of Yoga can create electrical flow in those pathways under the control of the person. In India, Yogis still exist who can control their nervous systems by the practice of *Pranayama* and thus keep their body cells fit for spiritual realisation.

GENERAL CONSIDERATIONS OF BIO-ELECTRIC POTENTIALS

Modern science believes in the presence of bio-electricity in the living system. The muscles, heart, brain, and nervous system generate electricity which can be detected with sensitive instruments. The output of electrical energy is negligible in quantity, but its presence has given physiologists an invaluable tool for studies of the activities of muscular and nervous tissues. In 1786, Galvani first claimed to have demonstrated the existence of "animal electricity". This subject has figured prominently in the path of subsequent physiological progress.

This electrical activity is a property of all living things whether they be plant or animal. It has been proved that all cells show, in varying degree, mechanical, thermal, electrical, and chemical activity. These are not independent activities. Mechanical activity is accompanied by thermal, electrical, and chemical changes. If we take into account one aspect alone, it gives an incomplete picture of events. This can be illustrated by the contraction of a muscle which can be recorded as movement or as nerve and muscle bio-electric potential. Whenever cortical activity is recorded electrically, the accompanying chemical, thermal, and mechanical changes are implied but often the non-electrical changes cannot be detected by present techniques. Even though the electrical aspect is very small, it can often be recorded because electrical activity passes readily through tissues and manifest itself at a distance, and because modern electrical techniques with the help of electronic gadgets have outstripped all others in dealing with exceedingly small currents.

A considerable amount of work has been done in recent years regarding the nature and site of the bio-electric potential. Hodgkin and Huxley as well as Curtis and Cole and their collaborators have presented physiologists with data which do not fit concepts of a single static membrane as the source of the bio-electric potential. The experiments which were done earlier had brought in various factors of membrane rectification and of inductance which can be coped with, at least in a formal manner, on the basis of classical views. Latest work reveals, on the other hand, that the membrane becomes either completely or largely depolarised during activity. It has been possible to measure the potentials of resting and active nerve with one electrode inside the fibre and another outside. These measurements represent the potential differences across the nerve membrane. The resting potential thus measured averaged 41 to 51 mv. The spike recorded from the same electrodes on stimulation of the nerve was as high as 95 to 168 mv. in the opposite sense. Tasaki has independently postulated values of 80 to 100 mv. for the spike of a single medulated vertebrate nerve fibre. Graham and Gerrard corroborated these results experimentally, after measuring the membrane potential of the squid giant fibre and on single muscle fibres. The data clearly indicate that during activity the potential developed across the membrane is not merely the abolition of a resting potential, but that the membrane becomes polarised in reverse order.

After much discussion, Hodgkin and Huxley came to a possible explanation that the difference between the action and resting potentials indicates a real reversal of potential at the surface membrane. Four types of interpretation may be put forward to account for the reversal of membrane potential during activity:

(*a*) the membrane becomes selectively permeable to anions which are present in the axoplasm,

(*b*) activity involves a change in the orientation of dipoles in the surface membrane,

(*c*) an explanation in terms of apparent membrane inductance, and

(*d*) the series capacity hypothesis.

It is unlikely that during passage of activity along an excitable tissue such as nerve or muscle the system will have reached anything like equilibrium. According to Teorell-Meyer and Siews theory, the membrane potential is a complex derived from mobile and immobile ions within the membrane. Meyer has suggested that bio-electric phenomena may be the resultant of the existence and morphological arrangement of both cation and anion selective membranes as well as of chemical reactions which may liberate or capture dissolved ions. That the bio-electric potential is more complex than can be accounted for by a simple boundary membrane is further indicated in the recently available work of Arvanitaki. The ultraviolet and polarisation microscope pictures given in von Muralts work reveal that neurofibrils penetrate the membrane. The validity of the hypothesis will therefore depend on demonstrating that, if the membrane does exist, it forms an ion selective polarizable structure.

Regarding nerve action through chemical intermediates: many hypotheses have been put forward in terms of the participation of specific chemical substances in the action potential. Von Muralt has brought together the evidence for at least three such "action substances": acetylcholine, thiamin (aneurin), and potassium. A very small quantity of acetylcholine appears to be liberated in the nerve during the passage of an impulse. About 10 times as much thiamin (vitamin B_1), which is located in the sheath, is likewise formed. Von Muralt believes that acetylcholine formation is essential for the excitation or recovery process and that thiamin is a reservoir substance closely connected with the formation and disappearance of acetylcholine. By making an assumption concerning the relation between the activity of the hydrolising enzymes and the ester, Nachmanson has gathered an impressive body of indirect evidence for his hypothesis. In recent work, strychnine and physostigmine, both of which inhibit cholinesterase reversibly, have been shown to abolish the action potential of squid nerve fibres reversibly. Another powerful inhibitor of cholinesterase, di-isopropyl flurophosphate (DFP) appeared to offer a direct, crucial test of Nachmanson's hypothesis, because DFP can inactivate cholinesterase irreversibly. In experiments with the sciatic nerve of the frog, it was found that the action potential was abolished by applying DFP but reappeared on removal of the substance. Because the inactivation of cholinesterase by DFP is not *immediately* irreversible, this crucial experiment against the theory has not materialised. The experiments with anti-cholinesterase do, however, strongly suggest that the acetylcholine-cholinesterase system enters quite intimately into the elicitation of the propagated action potential, not only of nerve but also of muscle. In studying the potentials of smooth muscle, Bazler is continuing his valuable work on the potentials of this complicated electrical system. Differential leads record potentials which have characteristics similar to those of other visceral smooth muscle. In the cat, spikes appear during moderate to strong peristalsis. The same description holds for potentials of the small intestine. Here, epinephrine first stops spike actively, but slow potentials persist as long as there is mechanical activity. Muscle from the intestine of the guinea pig responds only with spikes, and their frequency is related to the magnitude of the contraction. The contractures of frog muscle and their electric manifestations bring the data on visceral muscle closer into line with the better known skeletal muscle, for they show some similarity in behaviour.

Up to now, I have dealt with the general considerations of bioelectric potentials. I shall now proceed to take up the problems individually regarding brain, heart, and muscle.

A. BRAIN:

(*a*) HISTORICAL: Electrical activity in the brain of the living animal was discovered by Caton in 1874. He experimented with monkeys and rabbits and observed electrical fluctuations from the cortex. Beck, in 1890, demonstrated that the optic cortex of the dog liberated large potential fluctuations when the animal's eyes were illuminated, and that, in the absence of stimulation, smaller electrical fluctuations occurred which were not related to pulse or respiration. Gotch and Hornby (1892), while studying the localisation of functions in the central nervous system, also noticed the electrical activity of the cortex. Danilewsky (1891), Laionow (1898), and Trivus (1900) studied the electrical response of the cortex to various types of peripheral stimuli. Kaufmann (1912) reaffirmed the conclusions of previous workers and stated that the electrical fluctuations from the cortex are modified by sensory stimulation and are related to nervous activity. In 1906, Einthoven built a string galvanometer which was a tremendous improvement over earlier types of recording instruments. This, though principally used for electrocardiography, was first used by Nemainski for recording brain potentials. In 1925, Nemainski experimented with dog's brain and reported the electrical activity of brain and named it "electrocerebrogram".

Leading opinion in neurology and neurophysiology completely neglected the possibility of studying the electrical activity of the brain for almost forty years, from 1893 to 1933. Hans Berger, a German psychiatrist, however, did not overlook this possibility, and after several years, his attempts met with success. He was able to record for the first time the electrical activity of the human brain (1924). He published the results in 1929 but was not appreciated by the scientists at that time. He was, however, strong minded and continued his work and, in 1934, he demonstrated that the human brain has an electrical beat which comes from neurons.

The records showed that it changes with age, with sensory stimulation, and with various other changes accompanying the physicochemical state of the body. Normally, this beat appears as a mixture of a variety of waves of which some are sinusoidal fluctuations in voltage and frequency and the most easily recognisable rhythm has a frequency of 10 per second in adults. He called the latter waves "alpha" waves and demonstrated that they tend to disappear with attention or opening of the eyes. Faster waves, with a frequency ranging between 15 to 50 per second, were named "beta" waves. Like electrocardiogram, Berger named his record the "electroenkephalogram" which is translated into English as "electroencephalogram". The spread of this subject of electroencephalography was hampered due to studies on the recording of brief discharges in single fibres of peripheral nerves by the electro-physiologists. But when Adrian, a Nobel prize winner in electro-physiology, asserted the correctness of Berger's observations in 1934, electroencephalography become respectable.

The progress of the subject was much facilitated when the Harvard group started recording electroencephalograms of epilepsy cases (Gibbs, Davis, and Lenox, 1935). Grey Walter in England made a great advance by demonstrating that brain tumors can be localised by electroencephalographs through the unopened skull.

Now, the scope of electroencephalography is expanding and its application in various fields of medicine, surgery, and research is becoming very important. New properties appear with each increment in complexity of organisation from the simple chemical to the biological and from the single-celled animal to the highly organised society of cells called man. The pharmacologist cannot use purely chemical methods, and the neurologist cannot use purely biological procedures. Many problems in electricity are simplified by disregarding dimensional space. Electrical engineers have made great advances by developing fine sharp filters with which they can select a narrow frequency band, but a wide frequency range, undistorted by filters, is essential for electroencephalographic recording. The radio frequency range, which was already above the physiological, is still further removed now that the engineers' interest is centred on ultra-short waves and radar. By some scientists, the brain is compared with a transmitter and transformer of signals, by others, as an originator of signals. The use of electroencephalography in the case of epilepsy and other disorders is very important. But before going into abnormal studies, it is essential to have an idea of the normal EEG of this country. With that object, I have undertaken a project of studying normal EEG records. The records are taken from persons who are generally healthy with no history of head injury, encephalitis, convulsive disorders, or any family history of fits.

(*b*) INTERPRETATION OF EEG : The records from these subjects are classified according to age group. It is difficult to state the absolute normality of an electroencephalogram as the EEG of each person is unique. Although each person is electroencephalographically distinct from his neighbour in some particular, the primary concern is not with variations as such but with the type of EEG changes that are related to inequality. After recording 250 normals and another 280 abnormals, of which most were epileptics, the best discrimination between healthy and diseased groups was obtained by considering : (*a*) the appearance of paroxysmal discharges, and (*b*) the frequency and amplitude of activity, including factors relating to the amplitudes of different frequencies and the per cent of time that each is present. The nature of form, sychronysm, and topographical distribution are also considered. An EEG with a frequency of 8½ to 12 per second activity and no abnormally slow or fast activity is grouped as normal for adults. A variety of waves with notching and rectification with M or U shapes are not considered abnormal when the frequency range is between 8½ to 12 per second. The faster waves of low voltage with little or no recognisable frequencies are considered normal. An EEG with activity below 8½ per second, sub-alpha waves, which occurs in 8 p.c. of adult control subjects and 18 p.c. of epileptics, is classified as "very abnormal slow". These are the same type of seizure patterns which are classified as paroxysmal. The topographic specificity in localisation is added as an additional characterisation. If abnormality is definitely maximal in a given area, the EEG is considered as "very focal". One type of abnormality requiring special examination is asymmetry. By this is meant an unusual degree of difference between the activities of the homologus areas which, when considered alone, would not be abnormal.

(*c*) INFANTS AND JUVENILES : The infant and juvenile electroencephalograms show some focus or asymmetry, and those with seizure discharges are abnormal at any age. The incidence of slow and fast EEG varies with age. The adult classification must be adjusted for age if it is to be used for children. The method of frequency analysis of the EEG is very simple if one has learned to make these significant discriminations which distinguish between epileptic and non-epileptic persons. Once the patterns have been learned and the necessary engrams established, the problem of visual analysis becomes a fairly simple task of recognition—just like learning to read a new language with an unfamiliar alphabet and different kinds of script.

It has been found that in the EEG of a newborn child, while awake. low voltage slow waves are predominant. These slow waves increase in frequency and amplitude, until at one year, steady high voltage five to eight per second waves are common, particularly in the occipital areas. The increase in frequency continues with each succeeding year. By the ninth year, the records from the occipital areas usually look essentially like those of an adult. The frontal and parietal areas, however, still show at nine years of age much more slow activity than is common in normal adults. After 19 years, a majority of persons have normal adult types of activity in all cortical areas.

(*d*) MODIFYING FACTORS OF E.E.G. PATTERN :

[i] *Sleep :* During sleep in a normal person, there is an alteration in the pattern of cortical activity. The changes are related to the depth of sleep. I had the privilege of working on the sleep project of normal persons and took records of more than 60 subjects to study the changes which take place in a person from waking to a state of deep sleep. These were all adult persons and, in short, it can be mentioned that there were five different patterns of waves which appear before a person goes into deep sleep. There were differences in the EEG pattern corresponding to: drowsiness, very light sleep, light sleep, moderately deep sleep, and deep sleep.

As soon as drowsiness begins, it is characterised by flattening of and some slowing of activity in the EEG record (*i.e.*, generalised dropping of voltage). This is found in all subjects. Sometimes it consists of large slow waves in both frontal areas. The waves can be misinterpreted as a bifrontal slow wave focus. Their frequency is commonly one-half to two per second. In very light sleep, biparietal humps appear. They are high voltage spike-like waves, usually diphasic, and have frequency of 3 to 6 per second. During very light sleep, positive spikes and waves are common in the occipital region. In light sleep, bursts of 14 per second spindles appear along with 12 per second waves. Their highest voltage is in the frontals.

In moderately deep sleep, these spindles disappear and the EEG is characterised by irregular slow waves with a frequency of one-half to three per second mixed up with 4 to 8 per second slow waves. During very deep sleep, almost all activity is slow ($1\frac{1}{2}$ to 2 per second), though there is waking activity superimposed upon the slow waves. The slow activity is in phase in the homologus areas of the two hemispheres. Old persons do not develop typical irregular high voltage slow waves in deep sleep, but commonly have low voltage slow activity. Occasionally, in early morning sleep, the pattern is almost the normal waking one. According to Blake, *et al.* (1939), it was named the "null phase" because of the low voltage. In the series of recordings done by me, arousal response consists of a quick return to the normal waking patterns without transition through a stage of high voltage slow activity.

The evaluation of the EEG in case of sleep is sometimes difficult to interpret. The waking state activity tends to increase in frequency with increasing age. The 14 per second spindles and the $\frac{1}{2}$ to 1^{c} per second waves remain constant. In old persons during sleep, the EEG patterns resemble those of children, and they may, from the electroencephalographic point of view, be crudely called the "second childhood".

[ii] *Emotional States :* There are other modifying factors besides attention, age, and sleep, which cause change in the normal electroencephalogram. In emotional states, there are changes in the electrical activity of the brain, but they are sometimes difficult to discriminate from those that occur with attention. The electrical record of the sympathetic

activity in the hand and foot, known as the psychogalvanic reffex, and also the rates of the heart and respiration are more sensitive indicators than the electroencephalograph in evaluating emotional states.

It is a common practice in routine examination to include a period of 2 minutes hyperventilation with about 50 deep breaths per minute through the mouth. In susceptible persons, this procedure generally precipitates seizure discharges of three per second spike and wave type in petit mal epilepsy. Photo-stimulation is also used. The electroencephalographer has usually learned more, however, by leaving the brain unstressed and allowing it to manifest its own inherent rhythmicity and tendencies to dysrhythmia than by attempting to drive it. During World War II, certain lines of research were carried on in regard to the use of EEG as a screening technique to prevent epileptics from entering military service, particularly in the choice of personell for responsible positions. It has been found that in some patients with epilepsy it is possible to trigger a seizure discharge by sensory stimulation through one or more modalities ; much more common, however, are cases of epilepsy which develop seizure discharges with strong photic stimulation. Hyperventilation results in removing the carbon dioxide more rapidly than usual from the lung alveoli, and consequently from the arterial blood. There are certain homostatic mechanisms which normally protect the brain tissue against a fall in arterial carbon dioxide tension, but if deep hyperventilation is continued for a long period, the EEG becomes slow and there is a rise in amplitude. Sometimes the slow waves are prominent after, rather than during, hyperventilation. In children, this effect is more pronounced than in old age. In the EEG series of normals, this hyperventilation was included in all cases. Besides hyperventilation, there are other methods, like photic stimulation, by means of which the human cortex can be driven and controlled regarding its activity. A flickering light of strong intensity is held before the eyes, closed or open. As the flickering frequency of the flash increases, the frequency of the cortical rhythm increases, but the cortex is limited and cannot go beyond 30 per second. Tactile and auditory stimulation have been used to localise cortical response.

[iii] *Drugs*: Various drugs, like metrozol, can produce seizure discharges, but there are some commonly used drugs which may alter the normal electroencephalogram, e.g., caffine, bromides, and barbiturates in small doses produce fast activity. Such changes are also brought by alcohol, paraldehyde, *Canabus indica,* and high dosage of morphine. But in high dosage, all sleep producing drugs slow the EEG pattern so that it almost resembles normal sleep. In the recent studies on chlorobromazine with Dr. Werner, it has been possible to demonstrate magical changes in the EEG of monkeys and cats.

[iv] *Other related factors:* The activity of cortex is also modified by certain hormones, thyroid, etc., that are secreted in the body. At the middle of menstrual cycle, the cortical frequency is decreased. It has also been found that the electrical activity of the cortex becomes progressively slower during pregnancy, but rebounds after child birth.

(e) CLINICAL SIGNIFICANCE OF E.E.G. : It is thus found that electroencephalography is useful in neurologic disorders, epilepsy, organic brain diseases, and psychiatric disorders. It has been possible to record more than 200 cases of different varieties of epilepsy in our laboratory. Epilepsy, like diabetes, is a disease in a certain sense. Epilepsy can be diagnosed by the help of electroencephalography just as diabetes can be diagnosed by the clinical chemist. Epilepsy can be demonstrated as a paroxysmal cerebral dysrhythmia, and it is associated with disturbances of the metabolism of nerve cells. The chemical study of the brain is not sufficiently advanced to permit a detailed description of the chemical changes related to a convulsion. It may be regarded that the brain is a converter and distributor of energy. The main source of this energy is chemical, but one of its main products is electricity.

The causes of epilepsy are so numerous that a search for a single uniform etiology is futile. An injury of irritative degree can be produced by trauma, encephalitis, vascular disease, cerebral anoxia, brain tumor, abscess, or intoxication. Hereditary and constitutional factors are very important in this condition.

The role of bio-electric potentials is very important as the electrical activity which is recorded by the electroenoephalograph can give an indication of the nature of the abnormality of the brain, whether it is epilepsy, brain tumor, or other abnormal condition.

The progress in this field is a direct result of improved electrical recording methods. The main contribution is an undistorted amplification of several million times. This is coupled with a high time constant, by using resistance times capacity in the circuit, as high as one second, which ensures registration of subaudio frequencies and the lower end of the audio frequency scale. This combination makes recording of the very feeble and slow potentials of brain tissue possible.

In the series of recordings of normals and abnormals, I have used a Grass, Model IIID, 8-channel, EEG console in the research laboratory of the Department of Physiology of Calcutta University.

B. HEART :

(a) ORIGIN AND TRANSMISSION OF BIO-ELECTRICITY IN CARDIAC MUSCLE : Now let us consider the bio-electric potentials of the heart. It has already been stated that, when cells are at rest, there is no measurable discharge of potential in the surrounding tissue because positive and negative poles balance each other and an electric equilibrium exists. Any stimulation of resting cells leads, however, to "depolarisation". The permeability of a membrane changes and negative ions emerge from the cell and cause a negative potential on its surface. Owing to a. fundamental vital process, the membrane soon again becomes polarized, a process known as "repolarization". During depolarization (activation) and repolarization (recovery) of a muscle strip, potentials are formed at the boundaries between depolarized and polarized tissue. A part of the potential thus created reaches the surface of the body. It has been found that, with the spread of the excitation wave (depolarization) in the heart, potentials are transmitted through the body so that an effect is created as if doublets spread with the positive pole (source) preceeding the negative pole (sink). The situation is much the same as if a battery wanders while its positive and negative poles are close together. The arrival of a negative potential is preceeded by a positive potential. During repolarization, potentials are again formed at the boundary between repolarized and depolarized tissue, but the poles are reversed. The repolarization process proceeds at a slower rate, and the potentials created at a given moment are smaller. In the case when the muscle is at rest or is fully depolarized, it does not cause any measurable electrical effects.

The human heart is composed of a very large number of muscle bundles varying in size, running in diverse directions, and interlacing in manifold ways. A further very importat difference in the results obtained lies in the type of lead employed. In clinical examinations, the electrodes are generally not placed directly on the heart when recording the tracing. When the wave of excitation spreads over the human heart, considerable differences in potential appear. For the most part, they are neutralised by the blood inside the heart and by the surrounding tissue. Only a fraction can be intercepted and measured. The types of leads used are indirect, and the tracing is called an electrocardiogram or ECG. The amplitude of the deflection in the ECG denotes the voltage generated by the heart and only that which can reach the body surface is recorded. The site of the electrodes and the status of tissues surrounding the heart exert a very marked influence on the potentials which reach the surface of the body. Potentials developing along an axis which is perpendicular to the line joining two leads do not exert any influence on the electrocardiogram recorded in that lead.

(*b*) PRINCIPLE AND TECHNIQUE OF ELECTROCARDIOGRAPHY: Different types of electrocardiographs are now available. The principle of the apparatus is simple and generally known. If a powerful fixed magnet is employed and a fine movable conductor is brought into its field, the conductor will be deflected when a current flows through it. This principle is employed in the string galvanometer. A thin metal thread or a quartz fibre coated with metal is suspended between two poles of a powerful magnet. The action current of the heart is led from the person under examination and is conducted through this string, whereupon the movements of the string correspond to the direction and strength of the current. The vibratory movements of the string are magnified by means of a microscope and projected into a camera where they are photographed on a strip of moving paper. A small slit with a cylindrical lens in front of the camera aperture makes it possible to project the movement of a small section of the string on the photographic paper. In recording the electrocardiogram, potentials are involved which rarely exceed two millivolts. The amplifying thermionic tubes employed in the radio industry are used in electrocardiography, and the electrocardiograph is capable of amplifying the feeble cardiac voltage reaching the surface of the body about 3000 times. Some of these machines are portable and can be carried easily from place to place.

Earlier literature records that the current led from the human body to a galvanometer produced deflections, unequal in size and dissimilar in shape, depending on the parts of the body from which it was taken. In cases where connections were made at two points located near one another, or at two points lying symmetrically to the cardiac axis, no deflections were obtained because the two areas were at the same potential. There are innumerable points on the body surface from which leads may be taken. According to Einthoven, it is generally sufficient to take leads from the following points on the body surface to obtain a complete series of ECG. The points are the right arm, left arm, and left leg. The ECG from the right arm to the left arm is called lead I, that from the right arm to the left leg, which is approximately parallel to the heart, is called lead II, and that from the left arm to the left leg is known as lead III.

The ventricular muscle forms a cup, the opening of which points towards the right arm. The potentials formed by the activation of both sides of the septum more or less balance each other and, therefore, it is mainly the walls which are taken into account. The stimulus spreads along with specific fibres over the inner surface of the ventricles and then radially from within outward to the sub-pericordial layers of the myocardium. The right arm, being situated just opposite the opening of the cup formed by the ventricular orifice, receives mainly the negative potentials caused by the early activation of the inner layers of the myocardium towards which the stimulus spreads from the inside, and it first receives the positive potential from the front of the depolarization wave. The left arm receives only part of the potentials from inside the heart ; it is mainly the potentials from the lateral wall of the left ventricle which are transmitted to it. To the left leg are transmitted potentials from the outer wall of the right ventricle and from the part basal to the posterior wall of the left ventricle. Changes of the position of the heart in the chest, due to alteration of the position of the diaphragm, cause a rotation of the heart around its longitudinal or sagital axis, and hence there is a change in the contribution which these parts of the ventricular muscle make to the potentials at the extremities. As a rule, the right arm is relatively negative and the left arm positive. An upward deflection appears in lead I when the right arm is relatively negative. Compared with the left leg, a positive wave appears in lead II. A relative negativity of the left arm as compared with the left leg causes an upward wave in lead III. The heart is an involuntary muscle and it cannot be controlled or stopped if one desires. But in our ancient culture, the Yogis of this land could control the heart beat and sometimes keep it stopped for long periods. One such phenomenon in a Yogi was observed by me when the heart was completely stopped for 10 minutes. With the stethoscope, I could not find any indication of heart beat or heart sounds. By long experience, the nature of the heart beat in normal and abnormal persons can be distinguished. The notching of the waves in an electrocardiogram is indicated by PQRST waves. Each normal beat produces these waves and it has been found that P is the auricular complex and QRST the ventricular complex. The changes in the pattern, the time interval between each, and the time of the PR and QST intervals give a diognestic value to record, so here also we find that bio-electric potentials can give us a clue to the inner condition of heart.

(*c*) Some Applications of Electrocardiography : In studying the bio-electric potentials of the hearts of insects, it was possible to record the ECG of mosquitoes by specially prepared electrodes placed on the two ends of the tubular heart and connecting the leads to the ECG machine. This helped in finding out the seat of action of certain insecticides. I also took the ECG of fish, frogs, mice, guinea pigs, rabbits, cats, and monkeys, besides the various types of normal and abnormal human beings.

C. MUSCLE :

(*a*) Control of Muscles : Let us now consider the bio-electric potentials of voluntary muscles. The controlling centres are situated in different parts of the central nervous system. The muscles are controlled by motor cells lodged in the anterior portion of the grey matter of the spinal cord. The motor cells receive impulses from many other cells through their synapses, and each cell transmits impulses to the muscle fibres it controls through an axon process. The motor nerve cells and its processes constitute a lower motor neuron. If the theory is clearly recognised that these lower motor neurons form the ultimate path of all impulses acting upon the body, the problem of understanding the neuromuscular mechanism is less difficult. The body can only react to changes in its internal or external environments by means of muscles. So every stimulus must be transmitted to lower motor neurons controlling skeletal muscles. It can thus be appreciated that the seat of tension in visceral and skeletal muscle is determined by the condition of the body as a whole.

It has been found that each lower motor neuron, linked to a skeletal muscle, supplies a number of muscle fibres. The axon process of a motor neuron divides into branches when it enters a muscle and each branch terminates inside a muscle fibre as a motor end-plate. The nerve cell, its processes, and the muscle fibres are supplied from a motor unit. The number of muscle fibres supplied by a single nerve cell is variable in different muscles and also in the same muscle. In view of the all-or-none character of skeletal muscle fibre contraction, this arrangement is important and it allows varying degrees of tension to be produced in a muscle according to the number of motor units involved. The theory has been fully established that an impulse released within a muscle fibre stimulates either complete contraction of that fibre or that there is no apparent reaction. Partial contraction of the skeletal muscle is dependent, therefore, upon the number and size of motor units brought into play. Larger motor units, containing upwards of a hundred muscle fibres, may cause a relatively strong contraction of the muscle, whereas smaller units may produce finer movements. It has been suggested by a number of physiologists that whole fasciculi in some muscles may be controlled by separate motor units, while smaller units may supply groups of fibres within a fascicilus. The facts enumerated above relating to motor units are consistent with observations on the reactions of muscles in health and disease. The voluntary isolation of groups of muscle fibres by "muscle control enthusiasts" is clearly dependent upon selective control of motor units. They can isolate various muscles like the trapizius, pectoralis, rectus abdominis, etc. In various diseases, particularly anterior poliomyelitis, some fibres in a muscle may be affected while other fibres in the same muscle may not be involved. This fact is of outstanding importance in the treatment of diseases affecting skeletal muscles. Complete immobilisation of a partially affected muscle leads to deterioration of unaffected fibres and atrophy of related bone structure. When this method is adopted, circulatory stagnation and contraction of muscle connective tissue result in unnecessary lowering of metabolism and inhibition of healthy muscle fibres.

(*b*) CONDUCTION OF IMPULSES: Electrical impulses from all parts of the nervous system are constantly passing to the cells of motor units. In addition to the impulses from skin, muscles, joints, viscera, and brain, the motor cells receive impulses from different levels of the spinal cord. The lower motor neuron cell is linked to those many parts by means of synapses. It is generally believed that there is no direct continuity between any two neurons, and that impulses pass from one neuron to another across the minute bulbous axon terminations which lie around the cell walls and the dendrites. It is estimated that the motor cell may be surrounded by many hundreds of these synaptic endings, derived from posterior nerve roots, various levels of the spinal cord, and from the brain. The motor nerve cell has a large number of synaptic end-bulbs and dendrites on the surface of the cell body. The synapse is functionally important in that inadequate stimuli from other neurons may fail to build up sufficient intensity to "jump the gap" and are thus unable to influence the motor unit. Various theories have been put forward to explain how the transmission of an impulses across the synapse is modified, delayed, and controlled. Some authorities claim that inefficiency in the motor units in certain fatigued or diseased conditions may be due to impulses being unduly delayed or blocked at the synapses.

All these phenomena of the conduction of nerve impulses are mediated through bio-electric potentials which also accounts for any muscle fibre activity. In recent years, physiologists and clinicians have become fired with the possibilities of the various electro-diagnostic procedures, including the studies of muscle action potentials under the name of "electromyography". The study of the action potentials of skeletal muscle and the use of the electromyogram as an aid to diagnosis are becoming more common. Reports on electromyographic measurements correlate well with subjective reports of muscular relaxation. In abnormal conditions, the electromyogram has been employed for diagnosis, *e.g.*, tetanus, congenital myotonia, myasthenia graves, progressive muscular atrophy, sciatica, and infectious polyneurities. Fibcrillary action potentials result in the typical electromyogram of denervated muscle.

(*c*) POSTURAL REFLEXES: The application of electromyography is much used in the study of postural reflexes, to which the extensor reflexes are related, and they are regulated by nerve centres in the upper part of the cevical cord, medulla, and mid-brain. They may be classified into two groups: (1) stance (positional) reflexes, which cause static contraction of muscles to maintain the body in a definite position, and (2) balance (acceleraty) reflexes, by means of which impulses from the inner ear, eyes, and the muscles themselves enable the body to restore and maintain balance when it is disturbed.

Balance reflexes naturally play the main part in the body movements and may result in either flexor or extensor muscular patterns, according to the way in which the body has been placed off balance. The muscular response to balance stimuli varies greatly in different individuals. Those who have good "muscle sense" and are used to sudden balance changes are more capable of relaxing to a lower the centre of gravity. Many other persons are apt to stiffen when balance is suddenly threatened. It is true that fear also influences muscular reactions to a sudden change of the balance of body. When a man is drunk, the alcohol knocks the higher nerve centre "out of gear", so that control of movements, co-ordination, and balance are disturbed, and he fails to maintain an erect posture.

In industrial hygiene, it has been a problem to study the exact postures of a person at which one does not become fatigued easily by analysing mechanical stresses with the help of the electromyograph. The amount of muscular energy expended in performing movements depends largely upon the degree of skill which the individual is using in the particular movements under consideration. Unskilled movements involve dissipation of energy in contracting muscles not essential for the work being done, whereas the skilled performer employs a minimum amount of muscular effort. Skill in performing any type of muscle work is largely a matter of consciously or reflexly reducing the amount of voluntary muscle work and substituting reflex muscular action or elastic recoil of tissues and purely mechanical forces when possible, as no two persons have exactly the same degree of skill or same degree of physical development.

Postural muscle work involves maintaining and adjusting positions of various parts of the body to suit a movement. Work of this kind may mean static contraction, but in some parts of the body postural work involves movement of a part to maintain balance. So the muscles of the body are in different stress under different postures. Nowadays, with the help of electromyography, it has been possible to detect the nature of contraction of the muscle and its state, whether it is easily fatiguable or not. The method is not very complicated. Suppose one wants to study the nature of the bio-electric potentials of a contracting muscle: one will have to fix up two tiny electrodes on the surface of the muscle about 4 cm. apart, or use a concentric needle electrode, and connect the electrodes to an EMG machine. When the muscle is in a resting state, there is no deflection of the oscillograph pens, but, as soon as the muscle begins to contract, a spiky discharge at a rate of 20 to 25 per second appears. Ultimately, this rate may increase to 80 to 90 per second but it is never more than a hundred. It has also been noticed that the greater the force of contraction the greater the voltage (amplitude) of the spikes. It has been possible to detect the state of muscle in Yogic postures. Subjects were selected for investigation to ascertain whether there is any fatigue of the muscles which take part in a particular posture, *asana*. It is ascribed that a particular *asana* helps in the concentration of the mind and improves the circulation of visceral organs. Some *asanas* seem to be very difficult and generally cause great strain on the part of the subject. With the help of the electromyograph, records were taken from the skeletal muscles while subjects were in *asana*. Two groups of subjects were selected from a Yoga school and a school of physical culture and they were divided between the new students and those who had practised *asana* for a long time. In *asanas*, like *Sirshasana* and *Sarvanagasana*, the electromyographic picture of well practised subjects showed that the muscles of the back, thighs, and arms are in a state of perfect rest and that no spiky discharges are noticed in most of the cases. A few cases showed a 10 per second discharge, but it has been proved that muscles are not fatiguable at that frequency. It was found in cases of novices that the muscles of the back and thighs showed discharges of more than 20 per second. The bio-electric potentials thus generated can give a clue to the state of the muscle, whether it is easily fatiguable or indefatiguable.

CONCULSION

In conclusion, we find that the role of bio-electric potentials is one of controlling the whole organism, and the activities that can be recorded with special types of instruments give us an idea of the internal state of the brain, heart, or muscles.

The indispensibility of the brain and nervous system is not questioned. If this be so, then the fundamental significance of bio-electric potentials easily becomes apparent for, as I have pointed out, it forms the basis of all nervous activity. No form of biological activity exists which does not in some way involve the nervous system and hence bio-electric potentials.

I have attempted to consider in some measure the role of bio-electric potentials in the living system. In doing so, I have considered separately the problems with regard to the brain, heart, and muscles. In each case, I have confined myself to: (*a*) general principles and methodology of recording, (*b*) the nature of the electrical pattern and its variation under different circumstances, and (*c*) the clinical significance and interpretation of records.

These considerations in themselves hardly make the account a conclusive one. But then this cannot be expected in a limited period of time. On the other hand, it has been my intention to present to you an assemblage of facts which I hoped would illuminate the fact that this branch of physiology is pregnant with possibilities in the way of both fundamental research and clinical applicability.

We are privileged to belong to a nation of people whose culture dates from ancient times, and we have often been referred to as the people of the "mystic orient", principally because certain Yogic practices have made it possible to halt the heart, to remain buried alive, to live without food for long lengths of time, and so on, apparently violating the basic principles of physiology. These unusual activities are still in use by our Yogis for the purpose of "self-realization" and harmonious development of body, mind, and soul and are accomplished by controlling the body electricity. The physiologist in India holds a unique position in this respect and it rests with him to unfold this mystery.

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SECTION OF PSYCHOLOGY AND EDUCATIONAL SCIENCES

President :—RAJ NARAIN

PRESIDENTIAL ADDRESS

PSYCHOLOGY AND SECURITY

Psychological reflections on the problem of security have been in the past primarily concerned with the *feeling* of insecurity. It is, however, not with this feeling, important though it is for the welfare of the individual and society, that this address will directly deal. The problem of security in mind here is the familiar one of a nation-state being free from danger from without as well as from within ; of freedom from aggression or war from other nation-states, and from rebellion, revolt, or internal disorder of its members or sub-groups. In other words, the security under discussion here is that which military psychologists have made their especial domain ; and not that which is the theme of child psychologists or clinical psychologists.

Military psychology comprises diverse matters. The celebrated Gasiorowski[1] bibliography of army psychology[2] (of which only one copy is reported to exist in the States) lists the following :

1. Military psychology proper : psychology of soldier in peace and war, of army, of combat, and of war ; method of thought of the command.
2. Philosophy and sociology of war.
3. General (non-military) psychology of related fields : fear, courage, fatigue, honour, mass psychology ; educational psychology.
4. Psychotechnics and work psychology of military interest.
5. Military medicine, mental diseases, war neuroses, aviation medicine.
6. Morale.
7. Books on war : memoirs, letters, novels describing psychological aspects of war.

H. L. Ansbacher[3] in 1941 described the fields of military psychology in Germany as follows :

1. Sociological psychology dealing with the psychology of military organization, psychological advantages and disadvantages of different military systems, and certain psychological features of different types of military activity.
2. Job analysis and tools.
3. Characterological psychology of selection.
4. Education and training.
5. Morale, symbols and equipment.
6. Propaganda and psychology of other countries.
7. Psychology of combat and conduct of war.

The problems dealt with by Russian military psychology ("military psycho-physiology" to use the Russian term) were, as of 1936, those of intelligence, memory, fatigue, effect of equipment, selection of leaders and specialists, training, efficiency, group psychology, and neuroses.[4] A later report on the work of Soviet psychologists in war time by S. Rubenstein[5] refers to four principal ways in which psychology has been of help in war: (*i*) research in psychophysiology of sight and hearing in order to improve camouflage, intelligence work, and observation; (*ii*) research in the instruction and preparation of cadres of military specialists, above all in aviation; (*iii*) restoration of military and industrial fitness of wounded soldiers affected by cerebral traumata involving disturbance of language and thought functions, or by central and peripheral injuries involving impairment of motor functions of limbs; and (*iv*) research on motives of human conduct, of how the individual rises above the merely personal to the socially important, and how the socially important becomes personally important for him.

In the U.S.A., military psychology now (despite its neglect during the inter-war period)[6] is a big field of activity, with several branches and specialities. An idea of its comprehensive scope can be had from the seven fields discussed by *Psychology for the Armed Services*[7]:

1. *Observation*—the limits of accuracy in perception and the rules for getting the most accurate perception;
2. *Performance*—action and movement, the acquisition of skills, efficiency in work and action;
3. *Selection*—classification, choice of the right man for the right job;
4. *Training*—teaching and learning, the transformation of aptitudes into accomplished skills;
5. *Personal adjustment*—the individual's adjustment to military life, his motivation, his morale and his reaction to stress and fear;
6. *Social relations*—leadership, the effects and control of rumour, the nature of panic, the relations of peoples of different races and customs;
7. *Opinion and propaganda*—assessment of public opinion and attitudes, psychological warfare.

Of the several fields and facets of military psychology, this address will highlight Military Morale; Civil Morale; Psychological Warfare; and National Character only, because of the writer's special familiarity with Social Psychology, and because of a felt need to increase public consciousness of these areas.

II

Security is closely dependent upon the morale of the fighting forces and the civilian population of a nation. The morale factor was the chief cause for the collapse of France in World War II.[8] The relationship between danger and morale was strikingly brought out by E. Kris[9] in his study of the reactions of the urban English population to bombardment, and of the reactions of the British Expeditionary Force at Dunkirk. Before the war, and before danger became real, public opinion expected that man, under the threat to his safety, would likely develop psychological illness. Wartime experience corrected these assumptions. We learn that threat to safety was more easily overcome than threat to the social side of human life. Evacuation and not bombing, disruption of families and not casualty lists became the concern of those who were studying the morale problem in Britain.

The term morale, according to I. Child,[10] belongs to three different realms of discourse, and for each there is a definition as follows:

I. (Individual-organic emphasis): The term here refers to 'a condition of physical and emotional well-being in the individual that makes it possible for him to work and live hopefully and effectively, feeling that he shares the basic purposes of the groups of which he is a member; and that makes it possible for him to perform his tasks with energy, enthusiasm, and self-discipline, sustained by a conviction that, in spite of obstacles and conflict, his personal and social ideals are worth pursuing.'

II. (Group emphasis): The term here refers to the condition where there are clear and fixed group goals (purposes) that are felt to be important and integrated with individual goals; where there is confidence in the attainment of these goals, and subordinately confidence in the means of attainment, in the leaders, associates, and finally in oneself; where group actions are integrated and cooperative; and where aggression and hostility are expressed against the forces frustrating the group rather than toward other individuals within the group.

III. (Emphasis on individuals within the group on any specific occasion): Given a certain task to be accomplished by the group, *morale* pertains to all factors in the individual's life that bring about a hopeful and energetic participation on his part so that his efforts enhance the effectiveness of the group in accomplishing the task in hand.

Of the three definitions, the morale of the fighting forces and the civilians in war time is best represented by the third. Both civilian and military morale are based upon fidelity to a given task or cause; hence they react upon one another. However, according to J. A. Ulio,[11] there is a certain kind of morale that is distinctly military. It begins with the soldier's attitude toward duty and develops with the soldier's command over himself. It is a spirit that becomes dominant in the individual and also in the group.

High military morale is vital for national security. The conditions that make for high morale are: (*i*) attitude of (hero-worship) toward superiors; (*ii*) pride in group membership through possession of uniforms, insignia, parades and reviews, colours, close-order drills, mass singing, and unit athletic teams; (*iii*) relations of comradeship with immediate fellows, reducing boredom of routine work and tension of period of inactivity, enhancing feeling of security; (*iv*) other sources of positive incentives like medals and decorations, belief in the cause being faught for; (*v*) skills and knowledge of offense and defense leading to development of confidence and efficiency; (*vi*) and humour. It is interesting to note that the experiment of placing in the same regiment men who were congenial, who were interested in the same arts or crafts yielded "astounding" results in the German Army.[12]

Opposed to the conditions for high morale are those that lower the morale. Among the latter are: (*i*) reaction to killing in the form of guilt feeling; (*ii*) reaction to danger in the form of prolonged anxiety as well as momentary fear; (*iii*) deprivations of sex, physical comforts, normal social relationships and others not found in military life; and (*iv*) required conventions and activites, producing tensions and hostility.[13]

For purposes of security, it is essential that military morale be maintained at a high level. Morale-building is primarily a task for leadership.

The following rules were suggested to military leaders[14] in the U.S.A. toward this end:

1. Make each man feel he is needed by his unit, that his job in it is important.
2. Never let a man forget that he is a soldier, that a soldier of the Army of U.S. is an important and respected person.
3. Make it clear that the unit has its own important function in winning the war.
4. Encourage expression of pride in the achievement of the unit.
5. Give commendation and encouragement when it can be sincerely and appropriately given, for fair appreciation usually works better than condemnation.
6. Never belittle or humiliate a man in front of others except when a military emergency, as in a battle, may require quick correction. When a rebuke is necessary, do it in private, and make it clear that it is the act that is punished, not the man.
7. Keep idleness at a minimum, but make recreation possible.
8. Train each man in every useful task and action that actual combat will require and teach him that these habits will reduce his fear when combat comes, as well as make him a trained fighter.
9. Let men work together in groups whenever possible, because the social relation increases effectiveness.
10. Let the soldier on isolated duty feel that he is an indispensable man, not a forgotten one.

Since morale implies proper motivation, vigour and self-confidence, these are to be inculcated by such means as the following[15]:

1. Repeated emphasis upon issues of war and necessity for total defeat.
2. Deliberate and planned counter-propaganda to combat that issued by enemy.
3. Provision of best equipment and weapons, and exhaustive familiarization training in their use.
4. Explanation within limits of security of military plans and procedures.
5. Provision of best possible accommodation for mess in the form of food, clothing, shelter, mail delivery, entertainment, and post-exchange privileges.
6. Correction of grievances of soldiers, as far as possible, and sympathetic reaction towards others.
7. Time scheduling to reduce boredom and inactivity.
8. Liberal pass and furlough policy.
9. Justice in trial and punishment of offenders.
10. Comprehensive and efficient medical service.
11. Democratic relations between officers and men.
12. Opportunities for promotion, recommendation, and decoration.
13. Counseling and assistance in personal and legal matters.
14. Recognition of interest and capacities in classification and assignment.
15. Assistance to individuals in adjustment to military life by orientation, mental hygiene, and individualised attention.

The development of military morale in a democracy, according to R. A. Bortemarkle,[16] is dependent upon the determinants of individual strength of character. To guarantee the best possible military morale, individuals of strength of character must be selected for training. Selection on the basis of mere ability is not enough.

> Military morale in itself is one unit in the economic, military and psychological "tridimensional fields of action." The military phase proper possesses six stages: attitude to draft; selective training; anticipation of action; combat stage; and stage of reserve training for later preparedness. Morale at all stages may be influenced by material equipment and by personal factors, the latter divisible into actions and words. Under the head of action are forces of military routine, ceremony drill, etc.; under verbal devices are tradition, exhortation, propaganda, etc. Democratic, as opposed to totalitarian systems, can even "make use of the higher levels of character development" where the "whole man" takes part, and can use such devices as counseling and discussion.

The maintenance of military morale is beset with several difficulties. Military groups are marked off by four major characteristics: (*i*) one of the soldier's function is to kill human beings; (*ii*) a soldier is required to place his health and life in unusual jeopardy; (*iii*) a soldier is subjected to a number of deprivations; and (*iv*) a soldier is required to conform to a number of special conventions and to acquire certain special skills and knowledge, which assist him, or are believed to assist him, in performing function (*i*) and in maintaining his morale under conditions (*ii*) and (*iii*).[17] These characteristics present problems in building up morale.

The development of morale is not only necessary for combatants, but also for non-combatants. According to the complete observations of 81 individuals, W. A. Woods[18] came to the conclusion that morale is paramount in certain situations in which non-combatants are engaged. The raw military recruit enters service with concepts and hangovers from civil life which exert vast influence on his military morale. These influences tend to persist and affect him until or unless he finds new values for himself, or new values or satisfactions are provided him.

III

While the value of military morale as "the first line of defense and the last line of resistance" has long been recognised, the relationship of civilian morale to national security has but recently been established. Attention to the relationship was forced by the transformed nature of modern warfare. The war of today is not only fought upon battle-fields but in factories and farms as well. This means that the line that clearly divided military discipline from civil organization is obliterated, and the civilian's conception of his own role in warfare confused and changed. While subject to indiscriminate attack from air, the civilian is in as much need of morale-building as the soldier.

G. W. Allport[19] distinguishes civilian morale from military morale by the fact that the former is merely the morale of single persons supplementing the morale of persons intent upon solving the same problems; "morale" to him being a person's confidence in his ability to cope with whatever the future may bring. He also draws a distinction between segmental and integral morale. Segmental morale is of the hysteric type in which only certain segments of the personality are mobilized at the risk of severe conflict with the other segments and debilitating guilt reaction. Integral morale is that in which the whole personality is sufficiently at one to allow devotion to critical goals without conflict or recoil.

He at the same time urges the need for and promise of integral morale for democratic citizenry.[20]

For there is to him[21] a real distinction between democratic and totalitarian morale. Democratic morale possesses the following 11 features:

1. voluntary whole-hearted participation
2. respect for person
3. universalism
4. economic self-respect and social status
5. majority rule
6. representative and evocative leadership
7. tolerance
8. freedom of speech
9. the whole man
10. war never an end in itself, and
11. voluntary coordination of effort.

Goodwin Watson[22] points to five factors in morale. His approach to morale however is behavioural; "morale" describes what people do rather than how they feel. The factors are as follows:

1. A positive goal, a magnetic pole toward which the aspirations of men are drawn. Too little attention has been given to defining post-war goals. Morale has been based on negative factors: fear, hatred, anger; these are not enough.
2. A feeling of togetherness, sharing a common goal. Morale building demands discovery of common goals and national purposes and a sense of shared living, with social barriers removed.
3. Knowledge of common danger contributes to morale, as shown by effects of attack on Pearl Harbour.
4. Conviction that we can do some thing to improve matters; many do not know just how we can help, or how our daily activities further national purposes.
5. Sense of significant advance, well-authenticated knowledge that we are approaching the goal.

Studies of individual morale[23] of which civilian morale is compounded have led to the following findings:

1. Cyclical fluctuations in general feeling tone, with average period of three to nine weeks have been found in individuals.
2. Euphoric feelings are accompanied by more spontaneous remarks, expansiveness of movements in writing, quicker decision speed, more outgoing and energetic.
3. Questionnaire studies have established that higher morale is associated with higher occupational level and higher income.
4. Higher morale is associated with economic security.
5. Morale is related to age, through some consequence of age.
6. Morale is associated with certain living conditions, *e.g.* marriage, (students) living at home.
7. Conformity tends to go with high morale.
8. Deep religious convictions are associated with high morale.
9. Men possessing high morale use realistic techniques in seeking social advancement, as opposed to wishful thinking.
10. High morale is associated with enjoyment of leisure-time activities.
11. Men with high morale tend to be less intelligent.
12. High morale is associated with more education.
13. Health is not significantly related to morale.

The findings should help in chalking out a programme of civilian morale building. Doing this for America in 1942, G. Murphy[24] laid down the following essentials of the programme:

> The programme must be based upon something that most Americans really believe ; e.g. Jeffersonian tradition of democracy. The locus of such a programme should be both in a central administration, and in local, democratically functioning organizations. Immediate obstacles to good morale are apathy, scepticism, and inadequate standards of health and security. These can be combatted in part by dissemination of facts and by long-range planning both for war and peace to follow. Another essential is a positive programme of action continuously treating sick parts of economic system. Morale must be striven for on intellectual, labour, and business fronts. A central federal morale agency would be one of way of dealing with the problems that arise ; "failing this, the consolidation of morale work can be achieved through the co-operation of existing private services". A planned and co-ordinated social science research programme is basic to the success of morale service, present or future.

G. W. Allport[25] more pointedly prepared the balance sheet for civilian morale in America in 1941 in the following terms:

> Against the present morale is: the drawing up of a false parallel with the last war ; ravages of depression, including among some, violently antidemocratic attitudes ; national habit of destructive criticism and lack of respect for our leaders ; taking for granted of liberties ; habit of expecting personal profit ; distrust of democratic capacity for quick decision ; and factionalism.
>
> Working for positive morale are: American realism ; deep potential strength of democratic morale ; emerging of unity in national purpose ; American habit of intense co-operation ; hatred of tyranny ; finding of relief from anxiety in group co-operativeness in the emergency ; American sense of humour ; and American inventiveness.

Civil defense bears directly upon civilian morale. L. W. Kay[26] mentions the following five psychological considerations in planning civil defense in relation to civilian morale:

1. As soon as a locality has a civil defense programme, there should be a definition of the various tasks and a system of screening volunteers. The value of something to do for all should be realised, but jobs should be assigned so as to protect the greatest number ; screening of volunteers being a method of giving that protection.
2. Programmes of realistic public information, within the limits of national security, should be encouraged. Fear should not be used as the only or main motivation because it may lead to panic. Confidence in national goals and the ability to attain the goals should be built up through influential persons as well as through mass media.
3. All programmes for recreation and mental hygiene should be encouraged. Hobbies and recreational activities are morale builders. Recreation can contribute to well-being and bobbies 'give something to do'.

4. Officials and others who try to influence public opinion should first ascertain the state of current opinion.
5. A programme of research should be encouraged.

Civil defense services and agencies may cease functioning at the end of war, but the need for civilian morale building persists ; for hot wars tend to be succeeded by cold wars. "There is no *defense* against psychological warfare other than high morale and a consequent willingness to be critical in accepting disruptive material, even though it sounds logical."[27]

IV

Psychological warfare, i.e. the means for influencing psychologically the enemy, goes back to remote antiquity. The savage used tattooing, horrifying black-paint and instruments producing monotonous sounds capable of increasing emotional tension as well as of unlashing panic. In our times, psychological warfare has merely taken on a more technical character. The Germans, for instance, in the last war used in France lies, rumours, leaflets, front line loudspeakers, "poison pen" letters from home, screaming stukas, and other devices to undermine the morale of civilian and military forces. In the U.S. and Latin America, however, German propaganda aimed to divide the population and to inspire fear.[28]

The essential objectives of psychological warfare are to prepare a demoralising emotional tension in the enemy, to corrupt confidence in their leaders, and in their political and social system ; and to disunite the moral bases of their political and military organization. At home, the objective of psychological warfare is to exalt one's own national values, material or moral, focalise ideas, galvanise a national opinion, and attract thereby a collective libido.[29]

Some of the techniques used in modern psychological warfare[30] are as follows :

1. Data gathering in enemy territory to learn his strengths and weaknesses.
2. Cultivation of trust and confidence so as to facilitate such data gathering and allay suspicion.
3. Spreading of rumour in enemy territory, such as achievement by head-hiding gestures rather than by eternal vigilance ; cultivation of local intolerances, even by the committing of overt acts to cast disfavour on a government ; excessive self-criticism or defeatism. The psychologist need not attempt to cultivate new distrusts, arouse new suspicions, or turn hatred upon the well-beloved. He may select merely existing fears and purposes. He has to fan certain flames and to smother others, to make fire burn where he wants it, the fuel being supplied locally.
4. Fostering of defeatism, dis-illusionment, despair, weariness and cynical appraisal of war aims.
5. Promising a benevolent compromise. All adversaries of World War II poured leaflets, radio broadcasts, and underground rumours across battle-lines promising co-prosperity sphere and generous treatment of prisoners.

A detailed account of America's weapons of psychological warfare can be found in a recent book edited by R. E. Summers.[31]

Of the several weapons, rumour is easily one of the most formidable. It is most effective in ambiguous situations, and where needs are involved. It is used to disrupt morale, as a smoke-screen, as a bait, and to discredit news sources. Accustoming the public to trust official reports, developing faith in public and military leaders, giving as many facts as possible and fighting rumour mongers are tested counter-measures against this weapon. As a result of the use of this weapon thousands of refugees fled their homes in Palestine and Pakistan.[32]

An especially subtle method of spreading rumours is known as "black propaganda". It was used for the first time in Second World War. It asserts that it is being broadcast by secret radio stations operating within the enemy territory. Actually it is broadcast from another country. Such a station, having the advantage of irresponsibility, can broadcast scandals and rumours without discredit to its government. Black propaganda gets a sympathetic hearing from disaffected groups within the enemy nation. The most effective technique of black propaganda is to spread rumour by denying it or to put new ideas into the listeners' minds by arguing against them.[33]

> In 1940 black propaganda was used on the German troops in Norway. They were given broadcasts of health programmes. In one of them they were warned against eating potatoes which had been frozen, being told that in many people such potatoes induced a new disease called "potato grippe". The symptoms of the grippe were described as ailments which almost anyone is likely to have or to imagine he has, if he is worried about his health: headaches, eye-strain, muscular aches, coughing. Soldiers were warned to watch carefully for the development of such symptoms and to report them immediately, "because potato grippe in its later stages is extremely dangerous". The purpose of this broadcast was not merely to scare the soldiers away from eating an important food. It was hoped that the broadcast might help to create in them a hypochondriacal anxiety.[34]

Allied to black propaganda, and effective like it, is "combat propaganda". The intent of the latter is to break the *fighting* morale of the soldier. Some of the examples of combat propaganda used by the Allies in the last War are, as follows[35] :

1. Early in World War II, the Russians published a newspaper entitled *The Truth* for the benefit of German troops. By April 1942, fifteen million copies of it had been dropped behind enemy lines. German prisoners taken by Russians were found to have many of its issues ; i.e. were aware of Russian interpretation of the events in which they had participated. When information is not free, truth is often the best propaganda—as the Allies found in their broadcasts from North Africa to Italy.
2. German propaganda units broadcast to the French soldiers in 1940 the "news" that a commission from France was going to meet with the German authorities to sign an armistice. As a result the French troops reasoned: "Why hold the line and be shot today, when the war will be over tomorrow?" and the Germans made sweeping advances.
3. At the very beginning of World War II the Germans wanted the French to think that the war was "phony" and not to fight until Germany had got Poland out of the way. So their propaganda units began to encourage fraternization at the Maginot Line. They used their loud-speakers to bellow friendly greetings at the French and occasionally warned them that a shell was coming over.

In planning psychological warfare, certain considerations have been discovered to be important. P. M. A. Linebarger,[36] upon the basis of his study of psychological warfare in World War II, came to the conclusion that (*i*) psychological warfare is a function of command ; (*ii*) atrocity propaganda begets atrocity ; and (*iii*) America did not normally produce psychological personnel in peace-time, and if such personnel were to be needed again, they would have to be trained especially and in advance.

W. Eliasberg,[37] while analysing the relationship between German philosophy and German psychological warfare, has emphasied the point that psychological warfare had again and again to orient itself to a democratic point of view. "The political leader may resort to emotional fits. The military leader knows that his brain will stop working if brain storms take the place of cool reasoning." Pure idealism, of which Nazism was an expression, was confined to political propaganda at home ; while foreign propaganda and military psychology had ultimately to be realistic.

Donald V. McGranahan,[38] commenting in 1946 on the U.S. psychological warfare policy, disputed the wisdom of non-ideological lines of attack on the psychological warfare front. The Russians used a frontal attack on Nazi cause, and successfully. The U.S. policy seemed to be a reflection of the "advertising complex" whereby it sought to avoid offending the public it was trying to influence. In shrinking from an ideological attack this policy was wrong.

The need for strategic intelligence in planning psychological warfare cannot be overstressed. F. W. Williams[39] observes :

> Psychological warfare and strategic intelligence are closely related and while action in these areas is recognised as valuable, research on method and substance is extremely limited. Two major areas are important for research : knowledge about that which we want to affect ; and the methodology of affecting it. Related to both are problems of intelligence collection, appraisal, and evaluation.

The principal methods used in collecting strategic intelligence or "propaganda espionage"[40] have been listed as follows :

1. Many of the large nations maintain a well organised corps of agents and fifth-columnists where they would be useful in the event of war. In addition, friendly contacts can be set up with unsuspecting people by "tourists"—Germany ured this device notably in Norway long before the invasion of that land in Second World War. Such direct means are primary ways of obtaining information.
2. All important nations maintain listening posts for monitoring enemy's domestic broadcasts. What the enemy government is trying to make its people believe is important. Comparison of between enemy's short-wave broadcasts for reception abroad and his local long-wave broadcasts for domestic consumption may show what the enemy does not want his people to know.
3. Neutral countries in war time are exchange posts of information. Newspapers and magazines, even when rigidly censored, betray what people are doing and thinking. In Germany, e.g., when the wording of death notices of soldiers was changed from "Died for the Fuhrer" to "Died for the Fatherland" it indicated a change of sentiment. Later, when death notices were limited or cut out, that too proved significant.

4. For the correct interpretation of the information gained one has to have a solid background of the country from which it comes. One must know about the group affiliations there, the leaders' personalities, the economic relationships, the class frictions, the ideologies, the religious differences, and one must have command of the enemy language too.

The place of psychological warfare in insuring freedom from aggression and victory has been recognised by General Eisenhower in the following remark: "Without doubt, psychological warfare has proved its right to a place of dignity in our military arsenal."[41] Evaluating the role of psychological warfare in the collapse of the German Empire in 1918, G. G. Bruntz[42] has observed:

> While it is impossible to give percentages of victory to any arm of the service, it is evident that propaganda leaflets and news releases were among the most powerful weapons used. At the end of the war, Germany was well equipped and fed, but the morale was paralyzed. Evidence of this is found in letters sent home by soldiers, frequency of desertion, inertia, and insubordination in both civil and military populations, and in field observations of Allied and German officers and correspondents. "Good propaganda saved a year of war; and this meant the saving of thousands of millions of money and probably at least a million lives." Thus observed *The Times* of London in Oct. 31, 1918 issue of its paper.

More recently, in psywar in Korea, reports D. Story,[43] "nearly one-third of the Chinese and North Korean prisoners are said to have admitted to surrendering as a result of the psychological warfare effort.

V

While wars are actually fought by individuals, it is the nations that are at war. For the successful prosecution of war as well of peace, it is therefore essential to have knowledge of national psychology or character. In recognition of the need, World War II gave rise to many studies of national character. Several of these like Geoffrey Gorer's, Ruth Benedict's and Margaret Mead's have been published; but many studies by anthropologists have not been published; e.g. Ruth Benedict's studies of Roumania and Thailand, and Geofrey Gorer's study of Burma.[44]

Emphasizing the importance of such studies for military purposes, Margaret Mead[45] observes:

> The study of national character by anthropological methods can throw much light upon problems of immediate military importance in both direct and psychological warfare; contribute to the establishment of smoother co-operation with allied nations, and prepare personnel for problems of relief, reconstruction and world organization after the war.

Maurice L. Farber[46] states the several reasons for the study of national character as follows:

1. Increased acceptance of Freudian psychodynamics as an explanation of personality formation.
2. Development of projective methods of personality study with promise of intercultural adaptability.

3. Need, during the last war, for understanding the character of enemy and friendly nations, as well as of our own for purpose of predicting and influencing morale.
4. A similar need, during the post-war period, for knowledge both leading to international understanding to mitigate the possibility of war, and at the same time providing ammunition for current "cold war" or a potential future one.
5. Virtual exhaustion by cultural anthropologists of available undescribed pre-literate societies with their subsequent turning to literate ones.

The concept of national character possesses a number of close associates. According to Gorer,[47] the concept is almost synonymous with that of Kardiner's "basic personality structure" or basic character structure ; it is an attempt to describe and isolate the motives shared by the members of a society who manifest the same shared habits of culture. In his studies of national character, Gorer therefore utilizes Hull's learning theory and Freud's theory of individual psychological development, in as much as both the theories attempt to explain the "dynamics" of behaviour.

Ralph Linton[48] seems to equate national character with common-value-attitude systems. He says that the knowledge of the "basic personality" of various simple cultures studied by a combination of techniques drawn from various disciplines gives promise of establishing norms for a national character. When such common-value-attitude-systems are established as norms, they should permit fairly accurate prediction of the "behaviour of the average national in certain situations."

Erich Fromm,[49] however, advances the concept of "social character" for the understanding of cultures. "Social character" refers to the nucleus of the character structure which is shared by most members of the same culture in contradistinction to the *individual character* in which people belonging to the same culture differ from each other. "Social character" is not a statistical concept in the sense that it is the sum total of character traits to be found in the majority of people in a given culture. The function of social character, according to him, is to shape the energies of the members of society in such a way that their behaviour is not left to conscious decisions whether or not to follow the social pattern, but that *people want to act as they have to act* and at the same time find gratification in acting according to the requirements of the culture.

> The genesis of social character can be understood in terms of the interaction of economic, ideological and sociological factors. Inasmuch as political and economic factors are less easily changeable, they predominate in interplay. Religious, political and philosophical ideas however while rooted in social character, also determine social character and particularly systematize and stabilise it. Basic human needs rooted in the nature of man also play an active role in the interplay. While man can adapt himself to almost any condition, he is not a blank sheet of paper on which culture writes its text.[50]

Raymond B. Cattell[51] proposes the notion of "national syntality". In a factorial study of some 80 widely chosen variables gathered from 69 countries, he found some 12 dimensions of national syntality. For each of these 69 countries the factor endowment on each of the 12 factors was estimated so that a culture pattern profile could be constructed for each. This profile is said to define the *national syntality,* though it includes population and structural measures as well as measures of behaviour of group as group. Some of the dimensions are concerned with demographic or economic status, but most are concerned with what would be called the culture in the narrower sense of the term. Syntality is to a group what personality is to an individual.

Studies of national character have drawn their material from several fields: language, literature, history, sociology, anthropology, social psychology, and psycho-analysis and medicine ; they have utilised various techniques of investigation : field observation, content analysis, projective testing, psychiatric interviews, opinion-attitude questionnaires and community analyses ; and they have employed different schemes of organizing their material. Gregory Bateson,[52] for instance, believes that the concept of national character can be applied if individuals in a given community are described in terms of bi-polar characteristics and symmetrical patterns of interpersonal and intergroup relationship. Qualitatively differing combinations of such complementary motifs as dominance-submission, exhibitionism-spectatorship, succorance-dependence can be noted among English, American, and German cultures.

Despite the wealth of material and the variety of techniques, studies of national character are faced with serious methodological difficulties and questions. Klineberg[53] expressed his pessimism about the *scientific* status of such studies in the following terms:

> Stereotyped judgments are inadequate. McDougall's instinct theory doesn't help. Spengler's contrasts of cultures are inaccurate and oversimplified. The mental set of the journalist in treating of national character is void of proof. Treatment by anthropologist is better, but it is still judgment of one man. Mead's treatment of parent-child relationship to national character strikes at an important influence but lacks proof. Bateson's descriptions of bipolar characteristics (dominance-submission, etc.) in different nationalities seem probable but lack sufficient supporting data. The community studies by Lynds show promise but many more communities need sampling. The psychiatric analysis of the national mind, like that by Brickner, is plausible but not convincing. The slow, tedious methods, accurate measurements, adequate samplings, careful controls, and searching analysis used by psychologists in solving other problems should eventually bring satisfactory results in this field also.

M. L. Farber[54] has enumerated the methodological difficulties in studying national character as follows:

1. Nation is a political concept ; culture an anthropological one. The two don't always overlap. Character structure has meaning for culture only.
2. Nations exhibit marked historical changes in behaviour and attitudes. This would involve change in personality structure too. Cf. dry- and wet-rice culture change example. Studies of national character should have a definite time setting. Changes lasting a day or two cannot be considered.
3. Class differences may outweigh national differences. Nations are heterogeneous and not homogeneous. Kardiner's "basic personality structure" was designed for very broad cultural comparisons, not for study of national differences. The basic personality structure of Sophocles was that of the Western man. It was Linton who extended Kardiner's idea to study of national differences.

4. Political decisions are made by the elite or policy-makers ; they are atypical. Can we generalise from the acts of the Politbureau to Russian character? Hardly. But if we study the Russian character by taking the mass of Russians, the study would be useless from the point of view of applied psychology or social engineering for the masses do not make decisions. Little can be gained by influencing them through propaganda.
5. Personality traits are understandable in the context of social situations. Should we therefore study personality structure or social structure? Cultural products may include both.
6. The methodology of studies of national character is woefully lacking in scientific controls desired by experimentalists. One may be suspicious of monolithic causal schemes of character presented for example by Gorer of American character.

M. Ginsberg[55] points out that although ultimately national character must be linked with genetic qualities of stock, these are highly plastic and susceptible of wide variation in their actual expression. Hence national character is not something given once for all, but something always in the making, moulding and being moulded by circumstances in which nations find themselves. Studies of national character therefore should attempt to discover whether the manifestations of collective life reveal the existence of relatively permanent and stable traits and dispositions and how far these form a congruent system.

Fyfe[56] has characterised the search for national differences as illusional. A nation's character, its likes and dislikes, according to him, change rapidly and constitute little more than an illusion or fantasy fostered by literature and belief than by fact. The first concept of national character appears in the Old Testament, and the idea of the "country" developed about the middle of the 18th century because of the growing size and importance of the wealthy classes. The idea of national character is an illusion fostered by self-seeking rulers and despots because of its appeal to the least developed minds and as a justification for their suppressive measures.

Fyfe's criticism seems to be exaggerated. National differences exist and can be identified. As early as 1927, C. Landis[57] noted national differences in conversation.

> Fragments of conversation overheard on London streets as compared with similar conversations in New York and Columbus, Ohio, indicate that the same interests are exhibited by the Englishman as the American when conversation is between men, but that when talking to a feminine companion Englishman adapts his conversation to her interests, while American woman adapts her conversation to the interests of her masculine companion. English women talk more frequently of other women and themselves, while American women talk of men and clothes. Sex differences are as marked in London as in America, but there is a greater variety in conversations heard on London streets.

H. C. Lehman[58] has reported national differences in creativity :

> National differences in 11 kinds of contributions to science and art are studied by taking a "fair sample" of creative works regarded by experts within each separate field as of outstanding importance, and ascertaining the number of these contributions that have been made by individuals of a given nationality. No one nation was found to rank first in any 50-year interval in all 11 lines

> of endeavour ; during the last four centuries no one nation ranks first, as regards its total number of creative contributions, in all the 11 fields of endeavour. In most cases that nation which has attained pre-eminence most recently within a given field is also the nation which has achieved the greatest output within that particular field.

F. H. Lund[59] and W. C. Berg have shown that it is possible for college students to identify nationality origin and background of high school and college pupils with "better than chance" accuracy on the basis of general appearance alone ; and that this capacity increases with age.

D. V. McGranahan[60] and Ivor Wayne, upon the basis of their study of German and American popular drama, have found consistent differences between the two ; the differences appear congruent with pictures derived from other analyses as in politics and philosophy.

> In general German plays showed up as more idealistic, ideological, social-minded, and historical. Heroes are above society, and there are relatively few heroines (usually masculinized when they are). Love is idyllic rather than problematic, and moralism is infrequent. Resolutions in German plays are frequently in terms of power rather than "working-out" and while both plays emphasize the rebelliousness of their central characters, the Americans are rebellious for personal reasons while the German characters rebel for ideological reasons.

Charlotte Buhler[61] has noted the following differences among nations in "World Test" projection patterns :

Americans : complete aggressiveness in conflict with co-operative sociability.

Austrians : schematized aggressiveness in conflict with confused, open defenselessness.

English : inner coherence of aggressiveness in conjunction with seclusive closing off.

Dutch : withdrawal organized in strict, somewhat unimaginative order.

Norwegian withdrawal in an open, defenseless and unorganized individualistic pattern.

A. Kaldegg[62] has found differences in the responses of German and English secondary school boys to a modified form of the last part of Raven's Controlled Projection Test. The major differences were :

1. English boys were more detached ; only four out of the 129 studied dealt with test as a serious life situation.
2. Identification and loss of distance were more pronounced with German boys.
3. There was a tendency for the German S's to show greater conventionalism and rigidity.
4. German boys disliked cowards ; English boys disliked bullies, ruffians, and girls.
5. English boys showed less anxiety over school work and wrongdoing.
6. German boys showed strong agreement in the use of corporeal punishment for any offense whereas English boys showed a greater tendency to make punishment fit the crime.

VI

The foregoing discussion, it may be hoped, has succeeded in indicating some of the ways in which psychology can and does help in achieving and maintaining security. If the discussion is, not, however, to remain on the level of "verbal magic", certain lines of action need to be recommended. These may be stated as follows:

1. Military psychology should be recognised as a field of specialisation by the universities and the Government. This operationally means that the universities should institute courses leading to certification and/or training of military psychologists; and the Government should provide for a psychological service in the armed forces. A major task of the professional psychologists in the Armed Services would be research on the human factor in connection with the following problems:

> (1) Analysis of military tasks and occupations; (2) development of tests and procedures for selection, classification and distribution of personnel; (3) development of training programmes and of methods of evaluating training; (4) design and testing of instrumentalities of warfare (weapons, vehicles, airplane controls, radar, etc.) from the standpoint of personnel using them; (5) development of clinical techniques and procedures for individual examination and consultation services; (6) study of psychophysiological factors such as vision, hearing, and fatigue in the performance of specialised military tasks; (7) development of dependable techniques of ascertaining attitudes or opinions and procedures for use in orienting programmes, in morale services, and in psychological warfare.[63]

They may also be asked to supervise administration of practical programmes arising from the results of their research investigations.

2. Research in military psychology may also be encouraged in civilian institutions, notably the universities, by giving them contracts for specific projects. The projects may be worked out by the psychological wing of the Armed Services; or the wing may approve projects submitted by civilian psychologists. This is a pattern of research organisation that has been extensively used in the United States; and one which we may profitably employ. The universities would be only too willing to do their bit in promoting national security and welfare.

3. The teaching of psychology in the defense academies or other centres of military training should be made more comprehensive by including in its content the several aspects of military psychology; and an Advisory Board of Psychologists may be created to advise the Union Government on all phases of Army Psychology. The members of the Board should be able to spend considerable time in the discharge of their function.

4. In view of the crucial importance of morale for security, the Union Government may appoint a Commission on morale whose investigations may be both fact-finding and remedial.

5. Government should take immediate steps to control "propaganda espionage" of foreign nations; to censor "strategic intelligence" collected by outsiders; and to strengthen its information services in other countries for purposes of propaganda and counter-propaganda.

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SECTION OF ENGINEERING AND METALLURGY

President—B. B. BHOWMIK, M.Sc. (Cal.), M.Sc. ENG'G. (Lond.).

PRESIDENTIAL ADDRESS

HIGH VOLTAGE AND X-RAY EQUIPMENTS.

It is indeed a great privilege to preside over the Engineering and Metallurgy Section of the Indian Science Congress Association and I am thankful to you all for giving me this honour. This has a special significance. Whereas in other years either learned Professors or veteran Engineers have presided over this function, this year you have given the privilege to a manufacturer who is toiling hard in developing scientific industries.

I was sent abroad to specialize in X-Ray Engineering but unfortunately there is no proper course of X-ray Engineering in any University or Technical Institute. So I made up the course by prosecuting higher studies in High Voltage Engineering and taking practical training in factories where X-Ray machines are manufactured and in Research Laboratories and Hospitals where these machines are made use of. By profession I am manufacturer of X-Ray machines and as such I would have much liked to speak on the subject exhaustively, but as that might not be of any special interest to many of you, I shall discuss about the development of High Voltage Generators, in the first part of my address. In the second Part, I shall deal with the important aspects of X-Ray machines and the specifications of X-Ray machines best suited to Indian condition.

Though divided into two parts, they form the same subject matter because various types of High Voltage Generators that have been developed during the last 50 years came into existence mainly for the purpose of producing X-Rays for medical use and for physical and industrial research.

2. *Part I—High Voltage Generator.*

High Voltage has now become an important branch of science. In recent years great progress has been made and new methods have been developed for generation of high voltage and super voltage. Apart from their use in economic transmission of Electric Power, testing and researches on electrical machinery needed in High Voltage transmission, application of X-Ray and electron diffraction for crystallography and medical diagnostic radiography, application of penetrating rays for Therapy and industrial radiography, studies of atomic nuclei have given the greatest impetus to recent developments, and voltages to the order of 4 to 5 million volts are now in use in various laboratories of the advanced countries.

3. *Classification.*

There could be various ways in classifying these High Voltage Generators—one would have been as per their cronological developments, the other could be on the physical principles of their working but the simplest way of classifying them would, I think, be on their use.

4. *High Voltage for Power.*

4-1. For economic transmission of electric power from cheap sources of energy such a Hydro-electric stations or Thermal Power Stations in coal area to points of utilization higher and higher voltages are sought to, limited by insulation, corona, switchgear and other associated difficulties. In United Kingdom 132 K.V. National Grid System was the highest voltage used for transmission. They have recently introduced Super Grid to work at 275 K.V. In the Continent notably in Switzerland and Germany, 250 K.V. transmission lines are in use for many years. Long distance transmission line—a distance of about 300 miles has lately been installed in France to carry power from Genesia Dam to north of Paris at 250 K.V. Experimental transmission working at 380 K.V. is successfully working in Sweden for several years. Just before World War II, there was a scheme to tap the Hydro-Electric energy from the north of Scandinavia and to transmit the power at 500 K.V. and to supply the whole of Europe with cheap energy from these sources. Recently this scheme is being considered again with a view to give effect to it. The highest voltage at which transmission lines are working satisfactorily so far is 380 K.V. The energy at this voltage is raised by means of step-up transformers whose primary is fed by the Alternator generating energy at a voltage anything from 400 volts to 30,000. This is the highest voltage which a commercial Alternator has been designed to produce and the biggest transformer so far in use for transmission and distribution of power is of the order of 1500 MVA. output.

5. *Cascade Transformers (for Testing of High Voltage Gear).*

5-1. The standard specification for insulation test of high voltage gear is that it should be able to stand twice the working volts plus one kilo volt for one minute under certain conditions (the voltage being raised continuously from 0 to test value in one minute and the wave form being sine wave). This means that high voltage transformers and transmission gears which are to work at 132, 250 or 500 K.V. should be tested at 263, 501 or 1001 K.V. The manufacture of such transformer at power frequency and in single unit is difficult and apart from this difficulty, its cost is very high. The principal method of obtaining high voltage for such tests is by connection of H.V. transformers in cascade developed by Prof. Fredrick Dessauer, Director of the Kaiser Wilhelm Institute for study of the physical laws of medicine, University of Frankfort, Frankfort-on-Main, Germany. (Incidentally, I may mention that Prof. Dessaur left the country with the advent of Nazi power and was living in Turkey.)

Though the generation of high voltage by cascade connection of several H.V. Transformers is now mainly used for high voltage Engineering Test Laboratories and rarely used for X-Ray work but originally Prof. Dessaur was engaged in solving problems of high voltage generator suitable for energizing deep therapy X-Ray tube. He solved the problem and developed this new technique in 1915 and built up a set for 5,000,00 volts and to quote in his own words "which voltage I could have raised indefinitely". This he said at the 22nd Annual Meeting of the American Rontgen Rays Society, Washington D.C. Sept. 27, 1921 where he described this method in clear and simple way. The new principle developed though simple was of immense importance. In this method several suitable high voltage transformers are set side by side and secondary of the first transformer is (tapped at a suitable point and is) used as primary of the second transformer whose tank is insulated from the earth and kept at the potential of the secondary voltage of the first transformer. Similarly the secondary of the second transformer can be used as primary of the third transformer and whose tank has to be insulated from earth and kept at a potential of the secondary of the second transformer. Thus any voltage (A.C. at power frequency) can be obtained upto one or two million volts (further raising of voltage may cause practical difficulties). The real advantage of this method is the construction cost and the insulation materials and tank required in this method increases only by arithmetical progression whereas for the same voltage if obtained from a single transforer the insulation material and tank required increases by geometrical progression. Thus three 100 K.V. transformers connected in cascade will generate 300 K.V. and the insulating material required will be three times that of the 100 K.V. transformer where as if the 300 K.V. were to be generated from a single transformer the insulating material required would be 9 times (actually a little more) that of the 100 K.V. transformer.

Impulse (or Surge) Generator.

5-2. High voltage transformer and power equipments are not only subjected to over voltage tests of twice the normal working voltage plus one kilo volt, they are also often tested for their suitability to withstand surges (also known as transients) developed in the transmission line and transformers either by direct striking of lightening or by its near discharge or caused by switching-in sparks etc.

Marx circuit. This circuit is very much used for surge generators. It consists essentially of a circuit which enables condensers to be charged in parallel and discharge in series into a circuit containing the test object. The use of this circuit enables a lower charging voltage to be used for the generator and the individual condensers are more convenient than a single condenser would be if designed to give the full surge voltage. A simplified diagram of connections is shown in Fig. 5-2(1). T is a step-up transformer which supplies D.C. to the Generator through a valve rectifier 'K'. Very soon after the voltage is applied all the condensers will be charged to a voltage V say the condition, being as shown in Fig. 5 2(1). G1 G2 G3 are spere gaps G1 having a somewhat smaller separation than the others. At a certain value of V and depending upon its spacing G1 will break down and the voltage across the second condenser (between b and d) will rise to 2V causing G2 to breakdown and so on. Immediately after all the gaps have broken down condition will be as shown in Fig. 5-2 (3). Thus a test object connected between Q and earth will experience a voltage of 4V. It will be undesirable to connect the test circuit immediately to Q since this will mean that the test object would have a voltage V impressed on it until the gap flashes over. Thus it is customary to connect the test circuit through a further gap as shown in Fig. 5-2 (4). This gap breaks down when the voltage 4V appears at Q. In this way the voltage is not applied to the test object until breakdown of G1, G2 etc. has occurred.

Built on this principle surge generators of one to three million volts output are quite common in various test laboratories of West. Not only the voltage the amount of discharge current which a surge generator can deliver is of importance for such tests and research work. Various manufacturing firms use this circuit with slight modification here and there. Equivalent circuit of surge generator marketed by leading Electrical Manufacturing firms of England is shown below in Fig. 5-2 (5). In this circuit the wave-tail is largely controlled by R2 and the front by R1.

Surge generator with high voltage cathode ray oscillograph is an invaluable tool for researches on breakdown. That the breakdown may occur after the crest of the peak wave has passed may sound strange to many. As a matter of fact the exact mechanism of breakdown (of insulation) has not yet been fully understood by scientists. In the H.V. Laboratories of advanced countries all over the world tremendous amount of work is being carried out on these problems of breakdown by means of surge generator with H.V.C.R.O.

Before I pass on to the next chapter, it is worthwhile to make some observations here. The High Voltage Generators dealt with so far according to our present day convention falls under Power Engineering. In subsequent chapter Generators developing 4 to 5 million volts will be dealt with and in comparison to which a transmission voltage of 250 K.V. or 380 K.V. will look small and the problems associated will seem insignificant. The fact is not so ; because it has to deal with heavy power various difficult problem arises in dealing with it. Any mistake can cause serious accident even catastrophy. Whereas in dealing with super voltage of 4 to 5 million needed for atomic and allied researches, though it is also very highly dangerous but before it can do much mischief its own power in doing the mischief gets exhausted.

6. *Medium Voltage Medium Power Generator.*

Soon after the discovery of X-Rays by Rontgen in 1895 their usefulness in medical diagnosis was realized. Scientists also set down to study the physical properties of these rays and their scientific utilities. All over Europe and America new devices and contrivances were developed. Powers that used to be handled for X-Rays in those days were of the order of 5 to 30 milliamperes at voltages ranging from 30 to 80 K.V. or so. As cold cathode gas tubes were used in those days the current supplied to the tubes had to be made unidirectional. Though these devices are more or less of historical importance, a briefest possible description of a few important ones may be worthwhile.

6-1. *Induction Coil.*

6-1. Since the time of discovery of X-Rays till lately Induction Coils with an interruptor (generally rotating jet mercury) have played the most important role of H.V. Generator for X-Rays. Milliampere output of Induction Coil was limited. From gradual evolution of Induction Coil came the closed core Transformer and Induction Coils have become obsolete.

6-2. *Use of Batteries for High Voltage.*

For Medical X-Ray machine this is of theoretical importance because of prime cost of such a battery which must be made up of single cell of either primary or secondary type, expense of insulating materials for insulating these batteries and because of large floor area needed to house them etc.

However in America a 40,000 Volts Accumulator Battery of this type has been used by Blake and Duane (Phy. Rev. 9, p. 571 (1917) 10, p. 624 and 697 (1917) to determine exactly the voltages at which certain characteristic X-Ray spectral lines are emitted and incidentally to confirm the Einstein-Plank relationship Ve=hv. A tube current of 20 MA was obtained.

6-3. *Use of Capacity Switching Arrangement.*

This method was used by Trowbridge. He used a large battery of 20,000 lead storage cells giving a total voltage of 42,000. By means of this battery large air-condensers were charged in parallel each obtaining a voltage of 42,000. Then by use of a special high tension Commutator these condensers were switched in series where their voltages became additive and voltages as high as 3,000,000 were obtained giving sparks 6 or 7 ft. in length. The frequency of discharge could by means of inductance be reduced to 800 discharges per second. Trowbridge actually used his high voltage to operate a gas X-Ray tube.

6-4. Higher frequency electro-dynamic machinery and true high frequency high voltage current has been used as H.V. Generator for X-Ray. Influence machine of Weinhurst type about which something will be said in another chapter has also been used.

6-5 *Electro Static Voltage Multiplier.*

Another method of generating high voltage though of theoretical importance (and not connected with generation of X-Rays) worth mentioning because of the novel idea behind it. If a variable condenser is charged to a potential V1 when its capacity is C1 and if its capacity is then changed to C2 the voltage across the condenser becomes V2 where V2 is given by

$$V2=\frac{C1V1}{C2}$$

This can be demonstrated very nicely by connecting a Braun Electro-Static Voltmeter or an Electroscope across a variable air condenser. It also serves as a convenient method of charging an electroscope or any system of small capacity to a definite high voltage from a low voltage source. Used in this way the variable condenser becomes essentially an Electro-Static voltage Multiplier (Reference Alfred W. Simon Jour. Op. Soc. Am. 1924-25, p. 345 may be interesting).

7. *Voltage Multiplying Circuit.*

For deep therapy X-Rays and Industrial Radiography range of voltage used being of the order of 200 to 400 K.V. but since the milliampere load which a modern tube can stand at this voltage being limited to the order of 15 to 25 M.A. it becomes convenient and economical to use a 50 or 100 K.V. transformer and utilize different voltage multiplying (circuits) devices to get the requisite voltage than to use a single transformer of same voltage output. As a matter of fact almost all high voltage Generator working at voltage range 200 to 400 K.V. with an output of 15 to 25 M.A. use one or other voltage multiplying circuits.

In the early era of atomic research High Voltage Generators used were invariably of a voltage multiplying device. Higher and higher voltages were being applied to overcome the barrier forces inside the atom to get nearer the nuclii. Thus working in 1932 Sir John Crocoft and Walton succeeded for the first time in actually breaking the atom and reaching the nuclii by applying a voltage of 800 K.V. High Voltage at this time got a tremendous impetus. Voltage multiplying circuits were further modified and developed to provide generators to produce one million to two million volts.

Physical Laboratories of almost all advanced countries in Europe installed such high voltage Generators for atomic reseach. Kaiser Wilhelm Institute under Debye installed a 2 million volt plant. Cavendish Laboratory, Cambridge, installed 2 million volt plant and all these plants worked on the principle of voltage multiplying circuits.

Different combination of condensers and rectifying valves multiplies (doubles or trebles) the voltage of a transformer. Various combinations (circuits) have been developed by different workers and these circuits are named after them. A few important Circuits most widely used will be described briefly. Mention will be made only of lesser important ones.

7-1. *Villard Circuit.*

It is the oldest, simplest and one of the most widely used circuits. In Société Francaise de Physique, Seanees 1900 page 197 Mons. M. P. Villard described his circuit. In its simplest from the circuit is described in Fig. 7-1 (1). Two condenser, one valve is made use of in doubling the voltage of the H. T. Transformer. The drawback in Villard circuit is that the final voltage obtained is pulsating in nature whose frequency although is same as that of the cycle of H.T. Transformer. The nature of voltage wave in such circuit is shown in Fig. 7-1 (2). The Villard circuit can be further pushed up and Fig. 7-1 (3) shows a scheme of connection for a Villard unit to give pulsating tension upto 400 K.V.

7-2. *Greinacher Circuit.*

The advantage of Greinacher circuit over Villard circuit is that the ultimate voltage obtained from Greinacher circuit is constant in potential (with very slight ripples which can be chocked.) The circuit was developed in 1914 by Prof. Greinacher of Zurich University and was described in Verhandlungen Deut Phys. Ges. 1914 page 320. The circuit in simple form and wave form of the voltage is shown in Fig. 7-2 (1) and Fig. 7-2 (2). This circuit can also be pushed further to give higher and higher voltage. A scheme of connection for continuous potential unit in series to give upto 400 K.V. is depicted in Fig. 7-2 (3).

7-3.· Cockroft or Bouwers circuit to give 800 K.V. are shown in Fig. 7-3 (1) and 7-3 (2) :—

7-4. There are various other circuits such as the Witka circuit for trebling the transformer voltage. Mutscheller Circuit, Hull's Circuit. Each has own merits and demerits. But it is the Greinacher Circuit with some modification that has been mostly used to push up the voltage to million and above. One such circuit which has been developed and worked out by Kelley Koat U.S.A. is shown in figure 7-4 (1) :—

8. *Electro-Static Generator.*

8-1. The earliest machine to produce high voltage was Influence or Induction machine developed by Holtz, Voss, Varley etc. of which Wimshurst machine was tried to be made use of to some extent and the biggest one I saw at the Ecole Normal Supereur, Paris, dimeter of whose disc is of the order of 4 or 5 ft. Not being of much practical use these had no further development.

8-2. It was at the earlier era of Atomic Research when a novel development took place in America. Robert J. Van de Graaff with a band of collaborators developed a new method of supporting a large hollow sphere on insulators and running an insulating belt of silk or rubber inside the sphere, the belt being charged at 30 K.V. near the ground level or being charged by itself by induction. These charges are collected by a comb inside the sphere and the charge accumulates to produce very high voltage the only limit being the dimeter of the sphere and the insulating supports and the building space. The first of this type described in Phys. Rev. Nov. 15, 1931 page 1919 had an output voltage of 1,500,000 (1·5 million volts). This type Generator was constantly developed and improved to produce voltage of the order of 2 to 3 million volts. One such sphere charged positively and the other negatively would give a potential difference of 4 to 6 million volts. Whereas in Europe the voltage multypling circuit-was used for atomic research in America Electro-Static Generators were universally used for atomic research (these were of course superseded by cyclostron in later days). Its latest development has been in the contraction in size and housing it in a compressed air (or insulating gas) chamber and such Generators are also in use for X-Ray therapy. Picture of a latest model Generator is shown in Fig. 8-2 (1).

8-3. *Panthenier Generator.*

Another novel type of Electro-Static Generators were developed by Prof. Panthenier of Paris University under whom I had the good fortune of working in the development of a 2-million volt generator. Charges in this case are carried by fine silica powders charged at 12 K.V. driven by air turbine is deposited in the sphere. Some details of this generator is given below :—

Generators.

The first generator constructed on this principle was a very small one which delivered the expected current of 4 μA. and a voltage of 400 K.V. In June, 1936, the second generator was constructed with an aluminium sphere of 75 cm. diameter as collector. It was supported on two tubes of special Jena glass. The internal diameters of tubes were 10 cm. and their lengths were 210 cm. The two tubes were joined inside the collector by semi-circularly bent metallic tube divided into several sections. The sectioning of the tube has the double advantage of easier air-flow without eddies and of offering a larger surface on which the charged particles roll and thus discharge themselves completely. The ioniser used in this generator consists of 7 hexagonal steel tubes of thickness 0·5 mm., external side of hexagon being 17 mm. and their length being 35 cm. All the tubes were soldered together in the form of a beehive. Another aluminium sphere of 75 cm. diameter connected to earth was erected on wheels in order to make it movable for measurement of potential of the generator by spark-gap. Measured in this way the maximum voltage generated was 1200 K.V. and its output current was of the order of 50 micro-amperes.

The third generator was built for the Palais de la Decouverte (Palace of Discovery), and was exhibited at the International Exposition of Paris, 1937. The speciality of this generator was in the collector, which was not spherical. Though a complete sphere offers the best distribution of electric field and minimise the surface discharge, the entering of the tubes into the sphere collector distorts the field and causes discharge at much lower voltage at the joints of the tubes with the sphere specially when the tubes are made large to increase the output current. In order to avoid this, the geometrical form of the collector was made something like a flattened sphere, its equatorial diameter being 1·8 metre and its polar diameter being 1 metre. The ioniser consisted of 19 hexagonal tubes. The insulating tube columns were of porcelain of 15 mm. thickness.

The fourth generator on this principle was constructed at the University of Liege by Profs. Morand and Raskin, the collector being a large cylinder with rounded hemispherical ends. The dimensions of the room in which it was installed being small, the potential of the generator could not be exceeded over 450 KV. Though the diameter of the tube column was only 12 cm. the output current of the generator was 300 micro-amperes.

This current output can be doubled by modifying the construction of the generator in such a way that the collector is mounted at half way on the tube columns and the powder particles are charged twice, once at the lower end of the tube while going upward and again at the upper end of the second (descending) tube in the downward movement of the particles, the collection of charges from the particles being done by means of suspended needles in the middle of the tube covered by the collector. These needles are electrically connected to the collector to which all the charges are ultimately deposited.

A recent improvement of current doubling method by Raskin has been applied to a generator built and exhibited at the International Exposition at Liege. This generator is capable of delivering 800 micro-amperes and it is expected to go up to one milli-ampere after further adjustments.

The construction of the sixth generator on this principle was been finished at the Laboratoire Electrotechnique Generale, Paris University. It is characterised by several new features. The current doubling method has further, been extended for quadrupling the output current. Four tube columns have been used in series and four ionisers have been mounted in such way that the powder particles get charged and then traverse the collector depositing their charges on it four times successively per each cycle of their run. The arrangement is schematically shown in Fig. 8-3 (1) M is a motor driving the turbine S. I_1, I'_1, I_2 and I'_2 are ionisers. The collector is mounted at halfway on the tube columns. The charge collecting needles are seen inside the tube columns. At the extreme end of each tube column where the air-current changes its direction, a series of slightly curved parallel blades have been mounted for better air flow. The tube columns are made of pressed varnish paper (paper bakelite). A number of bakelite flanges have been (not shown in Fig.) fixed to the tube column to increase the surface and avoid grazing of sparks on the surface of the tubes. The collector is made of sheet aluminium and has a form of flattened sphere with a large rounded hole in the middle through which the tube columns pass. The generator is designed for 2·5 million volts and for an output current 2 milli-ampers at this voltage. Fig. 8-3 (2) shows a schematic representation of the generator. After this another new powerful generator has recently been set up at Bell Vue, France by Prof. Pauthenier.

9. In this brief space of time I have tried to survey the entire range of High Voltage Generators from which you will see what important role High Voltage is playing and what tremendous amount of work is being done in advanced countries. I have failed to understand why this subject is being neglected so much in this country when India is trying for rapid development in every sphere. With ambitious schemes for atomic-

power developments and for development of hydro-electric power and its transmission by high and medium voltage lines and ambitious schemes for radiological services for the masses, it is high time that this subject is properly developed both in teaching and industry. Leaving aside ambitious future projects, at the present stage of development it has become absolutely imperative that students coming out of Engineering Colleges should possess some knowledge and experience of high voltage. As a matter of fact, no Engineering College (teaching electrical engineering) should be considered to have a graduate standard of teaching unless it has high voltage testing set of at least 100 KV and students are allowed to handle this apparatus, for some practical work. A few experiments such as calibration of sphere gaps, measurement of dialectric strength of oil, breakdown test of a few small insulators will make them conversant with high voltage, and will enable them to cope with diffeient problems they may have to face in their practical field. At least this minimum has become essential.

PART II—X-RAY MACHINE

10. From the Engineering point of view an X-ray machine is a very interesting piece of apparatus and is highly technical in nature. There is high voltage, high vacuum, very short timing devices of the order of 1/10 to 1/100 of a second, switches to handle a load of 100 to 200 amperes within such short span of time, automatic metering and relays to make it foolproof as it is mostly handled by non-technical personnel.

As so many branches of Engineering are incorporated in it the subject is pretty vast. So I shall deal with some salient points of importance.

10-1. From my experience as an X-ray Engineer and manufacturer I give below some important points which are worth noting by power engineers.

(1) The output voltage of X-ray machines are always measured and denominated in peak value and in abbreviation written as KVP and in American as PKV. For instance one transformer which is designated in power engineering as 71·2 KV transformer will always be designated in X-ray work as 100 KVP transformer (the wave form being sine wave). The reason is whether the H.T. current is rectified by additional rectifier (Kenotron Valve) or not the current that passes through the tube is unidirectional and at peak voltage.

(2) For the same reason in calculating the power of an X-ray machine say designated as 100 KVP. 100 M.A. one should not reduce the peak voltage to RMS value and multiply by the MA because that will be wrong and will give misleading low figure. In this particular case it should not be 7·1 KVA but should be 10 KVA.

(3) Calculation made on this basis also will lead to wrong figure because allowance has to be made for losses in the transformer such as core loss, dielectric loss, corona loss (visible or invisible) because of low power and high voltage this allowance should be very liberal say 50% or over, i.e. to get full of 100 KVP 100 M.A. machine, a 10 KVA converter or supply mains will not be sufficient. 15 KVA converter or supply mains will be necessary to get full output of 100 KVP. 100 MA. machine.

(4) Majority of the X-ray machines are single phase machines and in A.C. area in order to avoid unbalancing the Electricity supplying company insists on taking load from 3 phase. In such cases one 3 to 1 phase 400 to 229 volts phase and volts reducing transformer is necessary. The 3 to 1 phase transformation is done either by Scott connection or by 'open delta' connection. Thus the 3 to 1 phase transformer is an "inefficient" trans-

former and moreover though it does distribute the load on the three phase but distribution is not equal on the three phase. So in calculating the power requirement of three phase supply mains for X-ray machine further liberal allowance should be made because of the 3 to 1 phase transformer.

(5) In calculating the load bearing capacity of cables for supply mains for X-ray machine, a Power Engineer is always guided by the heat generated in the conductor not to impair the insulation of the cables, and uses suitable cables as such but for X-ray machine specially for the diagnostic X-ray machine this is of little importance as the load is taken intermittently and that even for very short time say for a few seconds or fraction of a second. The guiding factor in selecting the cables should be the regulation of the supply lines (mains) i.e. the percentage drop of voltage from no-load to full-load should be minimum say of the order of 2½% or less and certainly not more than 5% because unlike power machinery like motors etc. an X-ray machine contains Kenotron Valves and X-ray tube which are electronic tubes requiring a small range of voltage for heating the filament for emission of electrons and these filaments remain heated before and after the main load is taken from the X-ray machine. If the regulation is bad, when load is taken the filaments get under-heated and either get damaged or restricts the output. If the filament heating is set under the load condition as soon as the load is over the filaments will be over-heated and may burn out. So the question of 'regulation' is very important.

(6) For the same considerations just discussed in the previous para, the line resistance should have a critical minimum value in relation to the power output of an X-ray machine depending on its impedance characteristic. This fact is not known to many experts in the line. Nowhere in the specification of X-ray machines of Europe and America, nor in the instruction sheets and booklets of manufacturing firms this is mentioned anywhere. This specification is stipulated only in the instruction sheet of Russian X-ray machines manufactured by the Ministry of Electricity, U.S.S.R.

11. Design of X-ray machine differs naturally according to the purpose for which it is to be used.

X-RAY DIFFRACTION PLANT

11-1. Voltage required is of the order of 50 KVP, as the characteristic radiation of all metals is obtainable within this voltage range. Milliampere output should be of the order of 30. This being the general capacity of sealed tubes. Capacity of demountable tubes of earlier days were of the order of 5 to 10 milli. Demountable tube with rotating anode tube has been developed to withstand up to 100 milli in which case transformer also should have this output. It is strange that reputed workers in the field of X-ray diffraction overlooks to study the engineering or electrical aspect of the machine and often puts too much value on the milliampere ouput of the machine which is completely misleading. Firstly X-ray Diffraction tubes have not reached a particular standard of efficiency (i.e. conversion power of the current into X-ray). Almost each tube at least tubes of different make differ. Secondly that the focal spot is an omportant factor is often overlooked. Other things being equal intensity of the X-ray beam will depend on the area divided by the milliamperes. So a smaller milliampere machine with small focal spot tube can produce more intense X-ray beams. Other factors to consider is the proximity of the anode to the window which should be minimum and windows should be of minimum thickness of low absorption material preferably of Beryllium because for the same thickness absorption of Beryllium is about 10 times less than mica or alluminium. That rectification, besides protecting the cables and tubes from dielectric loss (and thus increasing the life of the cables and tubes) also increases the load bearing capacity of the focal spot resulting in obtainable higher intensity from the same tube is not known to many.

Diffraction plant can also be used for micro-radiography work.

INDUSTRIAL RADIOGRAPHY AND X-RAY THERAPY (INTERMEDIATE AND DEEP THERAPY) PLANT

11-2. Voltage range used is 150 KVP to 400 KVP. Above 200 KVP voltage multiplying circuit Villard or Greinacher is used. For Industrial Radiography the focal should be very small. For therapy maximum output in 'R' should be the first consideration.

MEDICAL DIAGNOSTIC X-RAY PLANT

11-3. Due to wide use of X-rays in medical diagnostic work since the discovery, there has been regular and continuous improvement in the design and performance of X-ray machine. To-day an X-ray machine not only incorporates some of the latest marvels of engineering devices but in appearance also, it is so neat that it looks like an object of art.

H. T. Transformer of Diagnostic X-ray machine is centre earthed. Consequently, both anode and cathode are fed with high tension. The advantage is for 100 KVP set and the insulation problem to be solved is only for 50 KVP. The diagnostic X-ray tube has reached a standard of efficiency so that X-ray output can be well compared by milliampere loads. 50 to 90 KVP is generally used for radiography, though high voltage radiography upto 125 KVP has recently been introduced but its merits have not been proved by performance., KVP determines the penetrability of the rays and is selected according to the thickness of the part of the body to be radiographed. After selection of suitable KV a particular quantity of rays indirectly measured by milliamperes into seconds (Time) in short termed as MAS is required for taking radiograph of that part of the body and in Text Books on Radiography standard MAS are given for different parts of the body. But this is not scientifically correct because not only on milliampere, the intensity also depends on the KV and the size of the source. That KV plays a part is known to many by experience because by increasing KV lesser MAS is needed to radiograph the same part of the body (of course undue increase of KV will lose contrast). But the question of size of the source i.e. the area of the focal spot is often overlooked. It should be noted that with a smaller focal spot lesser MAS is needed to radiograph the same part of the body. Moreover smaller focal spot gives more details of finer structures.

EFFECT OF RECTIFICATION

In earlier days when cold cathode gas tubes were in use the high tension current had to be made unidirectional and then fed to the tube. Now-a-days with a hot cathode electron tube, the tube can simultaneously do the rectification of the h.t. current and produce X-rays, and machines incorporating such system, without use of rectifying valves, is known as self-rectified machine. Under such system if the milliampere load is high, the tungsten target of the anode may get too hot and start emitting electron in which case a current will pass through the tube in reverse cycle also (and electrical oscillation may start) damaging the tube or the H. T. Cable. Because of this local intense heating at points of the anode, the output of self-rectified machine is limited to 100 milliampere, but it is safer not to use more than 70 or 80 MA. So X-ray machines of higher output should always incorporate rectifying kenotron valves to rectify the high tension A.C. current of the H. T. Transformer before it is fed to the tube.

This rectification has added advantage. (1) Cost of modern shockproof tube and H. T. Cable is high and their prices together form a good portion of the total price of the machine. Rectification protects them from unwanted dielectric loss and prolongs their lives. (2) It is not known to many that rectification improves the wave form and the same focal spot can bear more load. 2 valve half-wave rectification increases the load bearing capacity of the focal spot by 50% and 4 valve full wave rectification increases the load bearing capacity to 100%. Thus a 2 valve rectified 100 MA machine with a X-ray tube of medium focal spot area 3·2 or 3·8 mm. can give very sharp details in the skiagram. But in a self-rectified machine to have 100 MA X-Ray tube should have a focal spot of atleast 4·2 mm. and skiagram will not be as sharp in details. These are the merits and demerits of valve rectified and self-rectified machines.

CATEGORIES

Classified as per their output, besides Dental and Fluroscopic screening unit, X-ray machines may be divided into six groups.

1. Portable machine—usual output 60 to 80 KVP, 10 to 15 MA. It should preferably be of 80 KVP 15 MA as in that case it can do skiagram of almost all parts of the body easily. The H.T. transformer, filament transformer and tube are all oil immersed and enclosed in a compact metal case.

2. Mobile machine—output 85 to 90 KVP, 25 to 30 M.A. Mounted on wheels to be moved about in the hospital ward so that skiagram can be taken near the bedside of the patients. The H.T. Transformer, filament transformer and the tube are all oil immersed and enclosed in a compact metal case as that in portable. Some manufacturers make the output of the mobile machine as high as 90 KV 60 MA with H.T. transformer and tube separated out and linked up by shockproof H. T. Cables. In this country such machine for mobile work is not very suitable firstly because the electrical plug point available at the bedside of the patient is not powerful enough to run the machine at full load. (As a matter of fact it is difficult to get full load of 25 MA output machine not to speak of 60 MA output) and secondly it is rather heavy to move about in the ward.

3. Low Medium Power Static Machine—output about 90 KVP 50 to 60 MA. Such machines are generally self-rectified low cost machine suitable for small hospital or for private practitioner where the pressure of work is not high. It can conveniently be used with two-position Table or low cost horizontal Table.

4. High Medium Power Static Machine—output 100 KVP, 100 MA. It should preferably be 2 valve fully rectified, as self-rectified machine worked above 70 or 80 MA is likely to give trouble for reasons already explained.

5. High Power Static Machine—output 100 KVP, 200 MA. (This machine should be 4 valve full wave rectified).

6. Extra High Power Static Machine—output 100 KVP, 500 to 1000 MA.

(Newly introduced high voltage radiographic machine of output 125 KVP is not taken into account as its working has not yet been standardized).

As there is no standard specification for X-ray machines nor any specification for suitability of combination for the machines with Table Units, I have tried to draw up some broad specification which is given in the appendix.

SUITABILITY

11-4. Considering the capacity of available electric supply in most of the towns, the economic condition of the country, and paucity of trained Radiologists, the hospitals should be furnished with moderately priced, robust, simplified (less complicated) X-ray machine of adequate power that will be able to do all standard Radiological work. Considering all these aspects the most suitable X-ray machine for a general hospital should be of following specifications :—

GENERAL SPECIFICATIONS

(*a*) 100 KVP, 100 MA, 2 valve, fully rectified shockproof X-ray plant with medium focus tube (having a minimum output of 100 MA at 85 KV for 1/10 of a second and continuous screening at 5 MA upto 85 KV and 4 MA upto 90 KV) and one modern tube Stand and a Table Unit consisting of one two-position Tilting Table with built-in Bucky and a Fluorescent Screen duly counter-balanced either on separate column or mounted on the Table.

(*b*) Secondly, in States Headquarters Hospitals and in Graduate and Post-Graduate Teaching Institutions 100 KVP, 200 MA, 4 valve rectified machine with all position Table with built-in Bucky, counter balanced fluorescent Screen, Spot Film and Tomography devices is desirable as 200 MA machine can do all work needed in Radiological Service.

Otherwise 500 MA machine is helpful for special work like angio-cardiography work provided full output of the machine is obtained. Since the only relative advantage of 100 MA, 200 MA and 500 MA machines is the comparative short time taken for skiagram of moving part of the body, such as, lungs and heart (say about 1/10th, 1/20th and 1/50th of a second, for 100, 200 and 500 MA machines respectively), extra high power machine of 500 to 1000 MA for routine work is not suited to our country at its present state. The 'high' power is practically useless because the electric supply or the line load capacity in this country is not sufficient to give full output of the machine and 500 MA machine costing about Rs. 70,000/- to Rs. 80,000/- if it has to be worked at 200 MA gives comparatively worse skiagram than 200 MA machine costing about Rs. 30,000/- and worked at 200 MA (because of focal spot-cum-sharpness relation). The colossal waste of public money done in this way may either be due to the false idea that prestige is enhanced by possessing a high power, high priced machine, or due to lack of technical knowledge of the subject and local condition or due to want of qualified and trained Engineers and testing facilities which often lead the Purchasing Department to think that the bigger the power, and the higher the cost, it 'must' work better. This view was also expressed in the Presidential address at the 5th Indian Congress of Radiology, the premier Radiological Association of India.

The Government in their keen desire for quick upliftment of the country is providing large sums for development and it is the duty of every one that things should be purchased from utilitarian point of view. To prevent such huge waste it is worthwhile to set up a committee to investigate how many 500 MA machines have been or are being purchased, whether full output of the machine is used, whether the electric supply condition at the place is adequate to give full output of the machine and whether a 200 or 250 MA machine costing less than half could not, in practical performance, do the same type of work which a 500 MA machine is contemplated to do, and also what new discoveries have been made with 500 MA machines.

Incompatible matching of machine with Table Unit often specified by the Purchase Department is another bar to efficiency and a cause of wastage. A few broad specifications for 'utility' type machines are given in the Appendix.

And finally, the manufacture of X-ray and Electro-Medical apparatus being an industry of national importance, the Government should give every help and support for further development.

I strongly believe that Indian Engineers and Technicians getting opportunity, can prove equally efficient and hold their own among such experts of other countries.

Jai Hind.

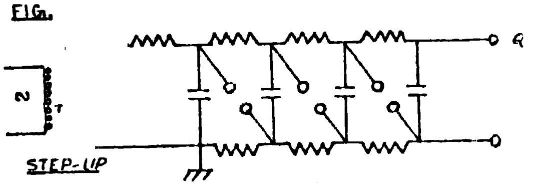

FIG. 5-2(1).

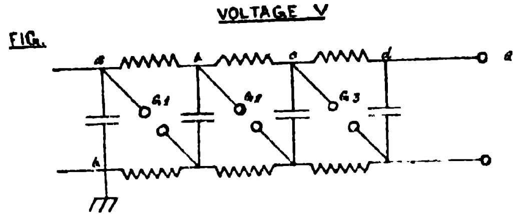

FIG. 5-2(2).

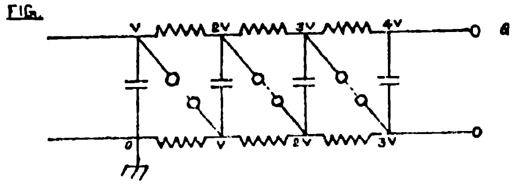

FIG. 5-2(3).

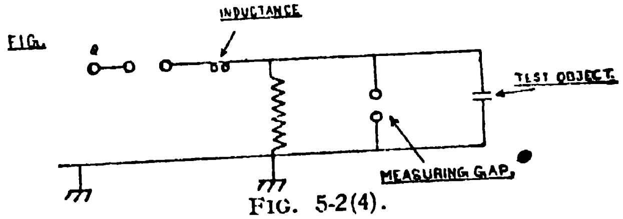

FIG. 5-2(4).

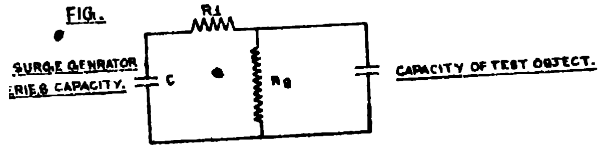

FIG. 5-2(5).
Equivalent circuit of a surge generator.

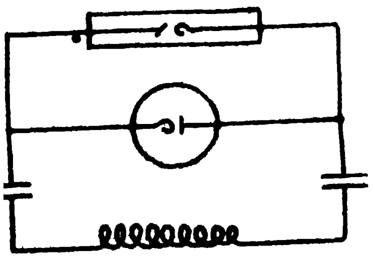

FIG. 7-1(1)
Villard circuit.

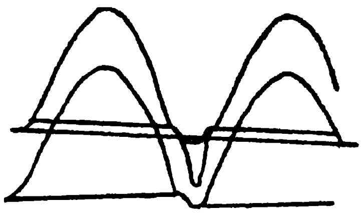

FIG. 7-1(2)
Wave form (approx.) of Villard circuit.

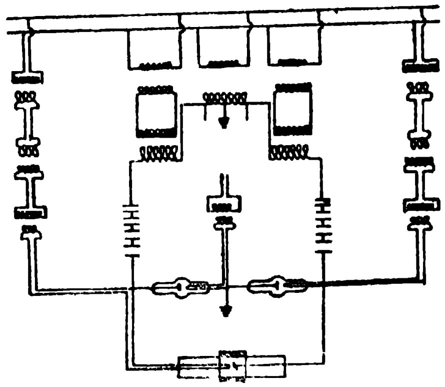

FIG. 7-1(3).
The scheme of connection for a Villard circuit to give pulsating tension up to 400 Kv.

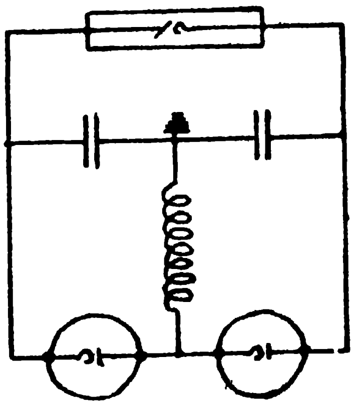

FIG. 7-2(1).
Greinacher circuit.

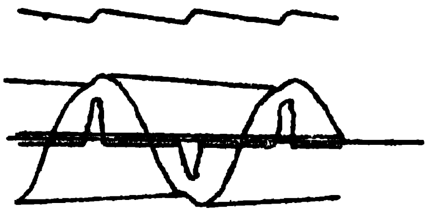

FIG. 7-2(2).
Wave form (approx.) of Greinacher circuit.

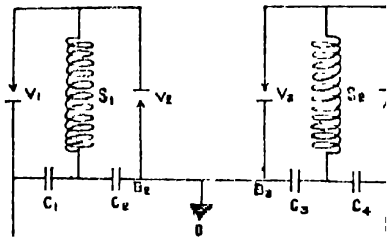

FIG. 7-2(3).
The scheme of connection for two continuous potential units in series to give up to 400 KV.

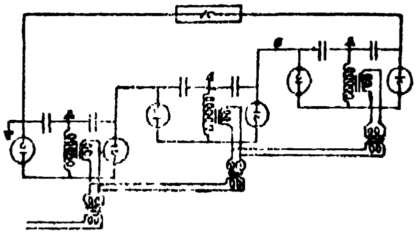

FIG. 7-4(1).
Extended voltage multiplying circuit.

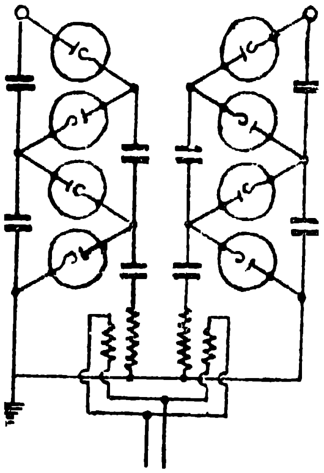

FIG. 7-3(1).
Bouwers circuit for 800 KVP.

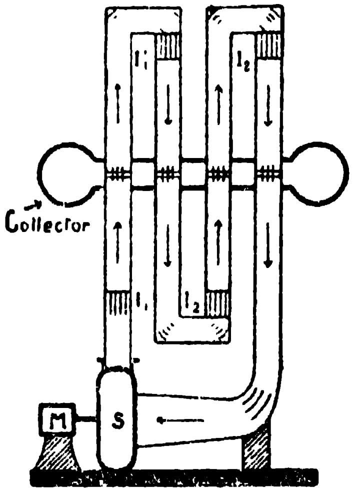

FIG. 8-3(1).
Schematic diagram of 2·5 million volt Pauthenier Generator.

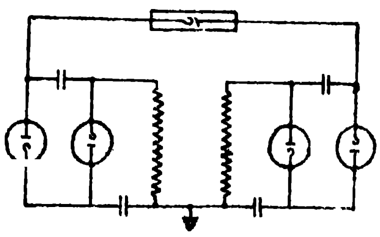

FIG. 7-3(1).
Bouwers circuit.

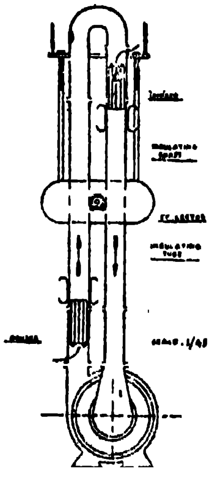

FIG. 8-3(2).
Side view of 2·5 million volt Pauthenier generator.

SECTION OF GEOLOGY AND GEOGRAPHY

President :—V. P. Sondhi, M.Sc., F.G.S.

PRESIDENTIAL ADDRESS

ASSESSMENT OF INDIA'S MINERAL RESOURCES-SOME RECENT ADVANCES

It is now twelve years that a review of India's mineral potentialities was presented to you by Dr. J. A. Dunn in 1943, when we were in the midst of World War II. Since then great changes have taken place in the social, political and economic structure of the world, in which India has had its full share. In the wake of these changes in this country, new values, new urges and new opportunities have emerged for the betterment of our standard of living, and among the lines of development which have been taken up with this end in view, a great deal of thought and endeavour has been put in the development of our potentialities in natural resources, of which minerals form a most important part.

I propose to give you here an outline of some important recent developments in this last field. These developments have been so many and so varied that it is not possible here to mention them all in detail. I will, therefore, confine myself to giving an outline of the results of our efforts at re-assessing the mineral potentialities of the country during the last decade or so. In doing so, I may be excused if I dwell on the process of development of the principal organisation which has been responsible for this re-assessment, namely, the Geological Survey of India.

Although notable contributions have been made by other agencies from time to time, in India the main responsibility for the supply of all data concerning the geology and the mineral resources of the country has rested with the Geological Survey of India, which during its over hundred years of laborious and systematic work has collected a vast store of information.

We were fortunate in starting our independent national existence with this reservoir of information and mature experience at our disposal for immediate use in the execution of our development plan. Be it a plan for the construction of a high, expensive dam across a far-away river in the hinterland, we already knew the general geological conditions obtaining in the area, and could quickly come down to detailed investigation of the foundations of the site, and also could quickly indicate the sources of materials for construction. Or, again, if the source of gypsum, on which was based the large fertilizer factory at Sindri, was lost to India because of the partition of the country, we knew exactly where to look for alternative sources within the new Indian boundaries, and were able quickly to make good the loss.

The need for a more adequate geological service in the country was, however, felt keenly during the World War II when there was a large demand for geologists for assisting the Army in locating air-field sites, road alignment, water-supplies and building materials etc., as well as for locating minerals which were in short supply. So far as mineral deposits were concerned, until that time, the general policy of the Geological Survey was merely to indicate broadly the potentialities of the deposits, leaving it to the private enterprise, or lessees, to ascertain more exactly the quantities and qualities of the ores by intensive prospecting in their respective concessions.

But it became necessary during the War to equip the Geological Survey for detailed prospecting, for carrying the work further to the stage of exploratory mining in selected areas, and in certain cases, where national interest demanded it, even for actually mining the deposits for production. Exploratory mining thus carried out by the Geological Survey at the lead-zinc deposits of Zawar, Udaipur, has now blossomed into a regular mining industry, with bright future prospects, and the mining operations carried out by the Department for the production of mica, sulphur, wolfram and beryl, etc. helped considerably to meet the war-time shortages.

The need felt during the War for more geologists in the country was felt even more strongly after the War when our national Government ushered in an era of all round development of the country's resources. More geologists were now required not only for the promotion of mineral and mining industries and for search for "atomic energy" minerals, but they were in urgent demand also for the large number of engineering and other projects such as dams, roads, railway alignments, water supplies and soil surveys. They were, in fact, required in larger numbers for most of the nation-building projects undertaken by the Central and the State Governments after the War.

The Mineral Policy Conference of 1947 further emphasised the need for intensive work on mineral development for ensuring increased production, conservation and utilisation of minerals. The chief outcome of this Conference was:

(1) the enactment of Mines and Minerals Act (Regulation and Development Act 1948) to replace the obsolete rules governing the grant of Mineral and Petroleum Concessions, and to bring uniformity of procedure in all the States which now comprised the Indian Republic.

(2) Further expansion of the Geological Survey of India and the setting up of the Indian Bureau of Mines in 1948 to ensure the development of mineral industry in the country on scientific lines.

Side by side, a chain of National Laboratories was set up to provide facilities for fundamental and applied research, those connected directly with the mineral development being the Fuel Research Institute, the National Metallurgical Laboratory and the Central Glass and Ceramic Research Institute.

In the Five Year Plan, the Planning Commission gave a high priority to the programme for the systematic exploration and assessment of mineral resources, improvement in mining methods and researches in beneficiation and utilization of minerals, and it urged for a further expansion of the Geological Survey of India, together with that of the Indian Bureau of Mines and the National Laboratories concerned for the implementation of this programme.

A Technical Co-ordination Committee was constituted to co-ordinate the work of the above three National Laboratories with that of the Geological Survey and the Indian Bureau of Mines.

In 1953, an All India Mineral Advisory Board was set up to advise Government in all matters connected with the development of mineral